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Impact of climatic variation on biomass accumulation in the boreal forest zone: selected references

E.B. Peterson, M.M. Peterson, and R.D. Kabzems

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IMPACT OF CLIMATIC VARIATION ON BIOMASS ACCUMULATION IN THE BOREAL FOREST ZONE: SELECTED REFERENCES

E.B. Peterson, N.M. Peterson, and R.D. Kabzems
Western Ecological Services (B.C.) Ltd.
Sidney, B.C.

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ABSTRACT

The literature on relationships between climatic variables and growth rates of boreal tree species was reviewed from sources in North America, the U.S.S.R., and the Scandinavian countries, with emphasis on information from Canada. An annotated bibliography of 329 references, covering references up to the end of 1981, provides background information for a synthesis of climatic factors or processes that influence boreal biomass accumulation rates, nonclimatic factors or processes that influence boreal biomass accumulation rates, influence of boreal biomass burning on atmospheric CO_2 levels, boreal climate-biomass relationships, and knowledge gaps.

Factors that influence growth rates of boreal tree species were grouped into those causing an increase in net primary productivity and those causing a decrease in productivity. Among the climatic factors, temperature-related variables exert more-obvious controls over primary productivity in boreal forest ecosystems than do moisture-related variables. Forest productivity changes induced by climatic variation may be masked by the growth-controlling influences of topography (aspect), soil moisture and nutrients, ecological succession, and forest fire history.

Among the many knowledge gaps pertaining to climate/biomass relationships, those of fundamental importance center around the linkages between fluctuating atmospheric circulation patterns and climatic conditions at regional and local levels.

RESUME

Une étude bibliographique des relations entre les variables climatiques et la croissance des essences boréales a englobé les publications nord-américaines, soviétiques et scandinaves ainsi que canadiennes surtout. La bibliographie annotée compte 329 références allant jusqu'à la fin de 1981 et constitue une documentation de base faisant la synthèse des facteurs et des processus climatiques et non climatiques qui influent sur l'accumulation de la biomasse boréale, de l'influence de la combustion de cette biomasse sur les concentrations de CO_2 atmosphérique, des relations entre la biomasse et le climat boréal et des lacunes de nos connaissances.

Les influences sur la croissance des essences boréales ont été groupées en celles qui favorisent une augmentation nette de la productivité primaire et celles qui la répriment. Parmi les facteurs climatiques, les thermiques régissent plus visiblement la productivité primaire de l'écosystème forestier boréal que les facteurs liés à l'humidité. Les modifications de la productivité forestière causées par les variations climatiques peuvent être masquées par l'effet de la topographie (exposition), de l'humidité et des éléments nutritifs du sol, de la succession écologique et des incendies antérieurs.

Parmi les connaissances qu'il reste encore à acquérir sur le sujet, les plus fondamentales concernent les relations entre les fluctuations de la circulation atmosphérique et les conditions climatiques au niveau régional et local.

FOREWORD

ENFOR is the acronym for the Canadian Government's ENergy from the FORest (ENergie de la FORêt) program of research and development aimed at securing the knowledge and technical competence to facilitate in the medium to long-term a greatly increased contribution from forest biomass to our nation's primary energy production. This program is part of a much larger federal government initiative to promote the development and use of renewable energy as a means of reducing dependence on petroleum and other non-renewable energy sources.

The Canadian Forestry Service (CFS) administers the ENFOR Biomass Production program component which deals with such forest-oriented subjects as inventory, harvesting technology, silviculture and environmental impacts. (The other component, Biomass Conversion, deals with the technology of converting biomass to energy or fuels, and is administered by the Renewable Energy Branch of the Department of Energy, Mines and Resources). Most Biomass Production projects, although developed by CFS scientists in the light of ENFOR program objectives, are carried out under contract by forestry consultants and research specialists. Contractors are selected in accordance with science procurement tendering procedures of the Department of Supply and Services. For further information on the ENFOR Biomass Production program, contact

ENFOR Secretariat
Canadian Forestry Service
Department of the Environment
Ottawa, Ontario
K1A 1G5

or a CFS research laboratory.

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CONTENTS

Forward
Abstract
Acknowledgments

1. INTRODUCTION 1

2. SYNTHESIS OF CLIMATE-BIOMASS RELATIONSHIPS IN THE BOREAL FOREST ZONE 2
   2.1 Climatic Factors or Processes that Influence Boreal Biomass Accumulation Rates 2
   2.2 Nonclimatic Factors or Processes that Influence Boreal Biomass Accumulation Rates 12
   2.3 Influence of Boreal Biomass Burning on Atmospheric CO_2 Levels 19
   2.4 Overview of Boreal Climate-Biomass Relationships 23
      2.4.1 Climatic change and climatic variability 23
      2.4.2 Successional controls over primary productivity 25
      2.4.3 Temperature and moisture controls over primary productivity 25
      2.4.4 Temperature influences upon distribution of the boreal zone 29
      2.4.5 Organic matter accumulation in boreal forest ecosystems 30
      2.4.6 Fire as an influence on primary productivity 31
      2.4.7 Local topography as an influence on primary productivity 31
      2.4.8 The complexity of growth-regulating factors in the boreal zone 31

3. KNOWLEDGE GAPS 33
   3.1 Unanswered Questions About Climatic Variation 33
   3.2 Unanswered Questions About Boreal Production Processes that Function Independently of Climate 36
   3.3 Research Questions on Relationships Between Climatic Factors and Boreal Forest Biomass 37

4. CRITERIA FOR SELECTION OF BIBLIOGRAPHIC SUBJECTS 41
   4.1 Overview of Subjects Included and Excluded 41
   4.2 Biomass of Boreal Vegetation 45
   4.3 Climate of the Boreal Zone 46
   4.4 Climate/Growth Relationships in the Boreal Zone 46
   4.5 Climatic Change in the Boreal Zone 46
   4.6 Climatic Variation within the Boreal Zone 47
   4.7 Growing Season of the Boreal Zone 47
   4.8 Tree-line Studies 47

CONTENTS (continued)

5. ANNOTATED BIBLIOGRAPHY OF REFERENCES ON CLIMATE/ BIOMASS RELATIONSHIPS IN THE BOREAL ZONE 47
5.1 Format of Annotated References 47
5.2 Indexing System 49
5.2.1 Geographic index 49
5.2.2 Species index 49
5.2.3 Subject index 50

ANNOTATED REFERENCES 51

CIRCUMBOREAL GEOGRAPHIC INDEX 344
MAP INDEX FOR CANADIAN REFERENCES 347
BOREAL FOREST SECTION INDEX FOR CANADA 349
BOREAL TREE SPECIES INDEX 351
SUBJECT INDEX 353

LIST OF FIGURES

Figure 1 Main study area within the Boreal Forest Region of Canada (Rowe 1972) shown on index maps based on the 1:1 000 000 International Map of the World (Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa) 3

Figure 2 Temperature-related isolines paralleling the northwest-southeast trend of the Boreal Forest Region in Canada (Rowe 1972) 5

Figure 3 Moisture-related isolines perpendicular to the northwest-southeast trend of the Boreal Forest Region in Canada (Rowe 1972) 6

Figure 4 Coincidence of boreal forest boundaries and air-mass boundaries in the present climate (Bryson 1966) 8

Figure 5 Net primary productivity ($g/m^2/yr$) in relation to mean annual temperature (°C) and mean annual precipitation (mm/yr) (Lieth 1975) 9

Figure 6 Variation in net primary productivity (t/ha/yr) within the Canadian Boreal Forest Region (Rodin et al. 1975) 10

Figure 7 Variation in net primary productivity (t/ha/yr) within the U.S.S.R. Boreal Forest Region (Budyko 1974) 11

Figure 8 Biomass (kg/m^2) and net primary production ($kg/m^2/yr$) in relation to evaporation, growing season, solar radiation, mean annual temperature, and mean annual precipitation in a north-south transect from tundra to semidesert in the east European lowlands (Walter 1968) 13

Figure 9 Partitioning of organic carbon in different climatic zones (Ajtay et al. 1979) 20

LIST OF TABLES

Table 1 Climatic factors or processes that influence biomass accumulation rates in boreal forest ecosystems 14

Table 2 Nonclimatic factors or processes that influence biomass accumulation rates in boreal forest ecosystems 16

Table 3 References (author/date) from this bibliography that provide data on biomass of boreal tree species 39

Table 4 Subject index for literature review of impact of climatic variation on biomass accumulation in the Boreal Forest Zone 42

1. INTRODUCTION

A literature review was initiated in July 1980 to synthesize presently available information on the impact of climate on biomass accumulation rates in the boreal forest region of Canada. Specific objectives originally stipulated by the sponsoring agency, the Northern Forest Research Centre of the Canadian Forestry Service, were as follows:

a) Assemble relevant biomass productivity and climatic relationships for a regional data bank such that the information may be used to project the effect of climate and climate fluctuations on biomass productivity;

b) to evaluate the inter-relationships between key climatic parameters and measures of biomass (phytomass) productivity in forest and adjacent agricultural lands;

c) to identify data gaps for future studies in the area of short- and long-term climate/biomass productivity interactions in the Canadian Boreal Forest Zone.

The original objectives quoted above were subsequently amended to incorporate two changes. Although information was summarized in a format that might lend itself to later conversion to a computerized data bank, the annotated bibliography was prepared by word processor in a form suitable for publication, with no immediate input into computerized storage. Secondly, at the request of the Scientific Authority at the Northern Forest Research Centre, the subject matter to be reviewed was expanded to include information on atmospheric input of carbon dioxide from burning of forest biomass in the boreal zone.

The reviewed information is presented in two ways in this report: first as an overall synthesis and secondly as a relatively detailed annotated bibliography. Section 2 of this volume summarizes known relationships between climatic variables and measures of net primary productivity or biomass in forested boreal ecosystems. From the identified relationships between climate and net primary productivity, the reader may infer the changes to boreal biomass accumulation that might accompany a known or assumed variation in climate. Some of the more conspicuous unanswered questions are identified in Section 3, although the annotated bibliography must be consulted for details about knowledge gaps.

Section 4 describes the criteria that guided the selection of references for inclusion in the bibliography. Section 5 outlines the indexing system used at the end of this volume and describes the format of annotations in the bibliography.

The main part of this volume is the annotated bibliography that summarizes published information on biomass (standing crop), net primary productivity, climatic factors that influence rates of net primary productivity, and nonclimatic factors

that influence biomass accumulation in the boreal forests of North America, the Scandinavian countries, and the U.S.S.R. Most emphasis was on information for the boreal zone in Canada, as outlined in Figure 1. Vegetation zones identified in the literature as subarctic, taiga, or forest-tundra were considered to be ecologically comparable to the boreal forest region of North America. The emphasis was on forested ecosystems, with only a limited review of productivity in unforested peatlands and in agricultural lands that lie within the boreal region.

2. SYNTHESIS OF CLIMATE-BIOMASS RELATIONSHIPS IN THE BOREAL FOREST ZONE

In comparison with most other natural woodlands, the northern coniferous forests of the boreal zone are low producers, with a net primary production ranging from 2 to 20 t/ha/yr and a biomass ranging from 80 to 500 t/ha (Jones 1979). Because of the geographic immensity of the circumpolar boreal zone, it contains a significant portion of the total global plant biomass. The total plant biomass on land is estimated to be 2.4×10^{12} t, dry weight, and the total in the oceans is thought to be about 1.7×10^{8} t, which is about 15 000 times smaller than that on land. Of the total land biomass, 56% occurs in the tropical zone, 18% in the boreal zone, 14% in subtropical forests, 12% in north temperate forests south of the boreal zone, and 1% in tundra zones (Rodin et al. 1975).

The purpose of this study was to assess the impact of climatic variation on biomass accumulation in boreal forest ecosystems. This task required a review of all factors that cause changes in primary productivity rates and then an assessment of which factors act in response to climate and which act independently of climate.

The identified factors were grouped into three categories in relation to climate/plant growth relationships:

a) climatic factors that directly influence survival and biomass accumulation rates of boreal tree species;

b) nonclimatic factors that influence boreal biomass accumulation rates apparently independently of climatic patterns; and

c) nonclimatic factors that influence boreal biomass accumulation rates but which themselves may be triggered or regulated by climatic events.

2.1 Climatic Factors or Processes that Influence Boreal Biomass Accumulation Rates

It is well documented that the distribution of the boreal zone, and particularly its northern limit, is climatically controlled. Numerous maps reveal the geographic similarity between the circumpolar boreal zone and isolines of a variety of temperature-related parameters (Hustich 1953). The latter include

Figure 1. Main study area (shaded) within the Boreal Forest Region of Canada (Rowe 1972) shown on index maps based on the 1:1 000 000 International Map of the World (Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa).

measures such as mean annual length of growing season, dates of the last freezing temperatures in spring and the first freezing temperatures in autumn, isotherm of the warmest month above 10°C, summation of degree-days above 10°C, and southern limits of permafrost zones. Rowe (1972) showed the close geographic relationship between isolines of the number of days in the growing season and the northwest to southeast trend of boreal region boundaries in Canada, as shown in Figure 2. The length of the growing season is important in tree growth, and its influence can be enhanced by either a warm period in spring or by a moist period in late summer. Some researchers have stressed the influence of local factors upon length of growing season and have suggested that each tree responds to its own local microclimate, which apparently differs somewhat from the microclimate of each nearby tree (Mitchell 1967).

In contrast to temperature isolines, moisture regions in Canada's boreal zone are characterized by generally north-south isolines (Figure 3), indicating that the boreal zone is not distributed according to specific moisture indexes (Rowe 1972). There is a notable contrast between the directional trend of moisture-related isolines in North America and in the U.S.S.R. The high mountains along the southern border of the U.S.S.R. rule out the intrusion of warm moist air masses from subtropical latitudes and add to the continentality, which is expressed in terms of reduced precipitation. The east-west orientation of the mountains also causes a moisture zonation that is perpendicular to that in eastern North America. In the latter case, the temperature zones run generally east-west, while the moisture zones run north-south. In the U.S.S.R. they both run east-west. Thus in North America the moisture and temperature gradients are perpendicular to each other, while in the U.S.S.R. they are not. This means that the U.S.S.R. offers fewer moisture and heat combinations than does the eastern part of North America (Lydolph 1977).

Although temperature-related variables exert the dominant climatic controls on tree species distributions and growth rates in northern portions of the boreal zone (Mikola 1962), there is evidence that moisture-related variables are increasingly influential near southern limits of the boreal zone (Mathews 1976, Mikola 1956, Schove 1954, Thammincha 1981). Similar trends are revealed in altitudinal gradients of mountain regions where temperature is a dominant control over tree growth near the altitudinal timberline, but available moisture is a dominant factor at lower altitudes in the valleys (Hoeg 1956, Lamarche 1978, Powell 1981).

There has been much emphasis on air mass analyses in the search for relationships between climate and boreal vegetation, as exemplified by the work of Bryson (1966) and Barry (1967). There is an apparent coincidence between the northern tree line in Canada and the modal July position of the arctic front

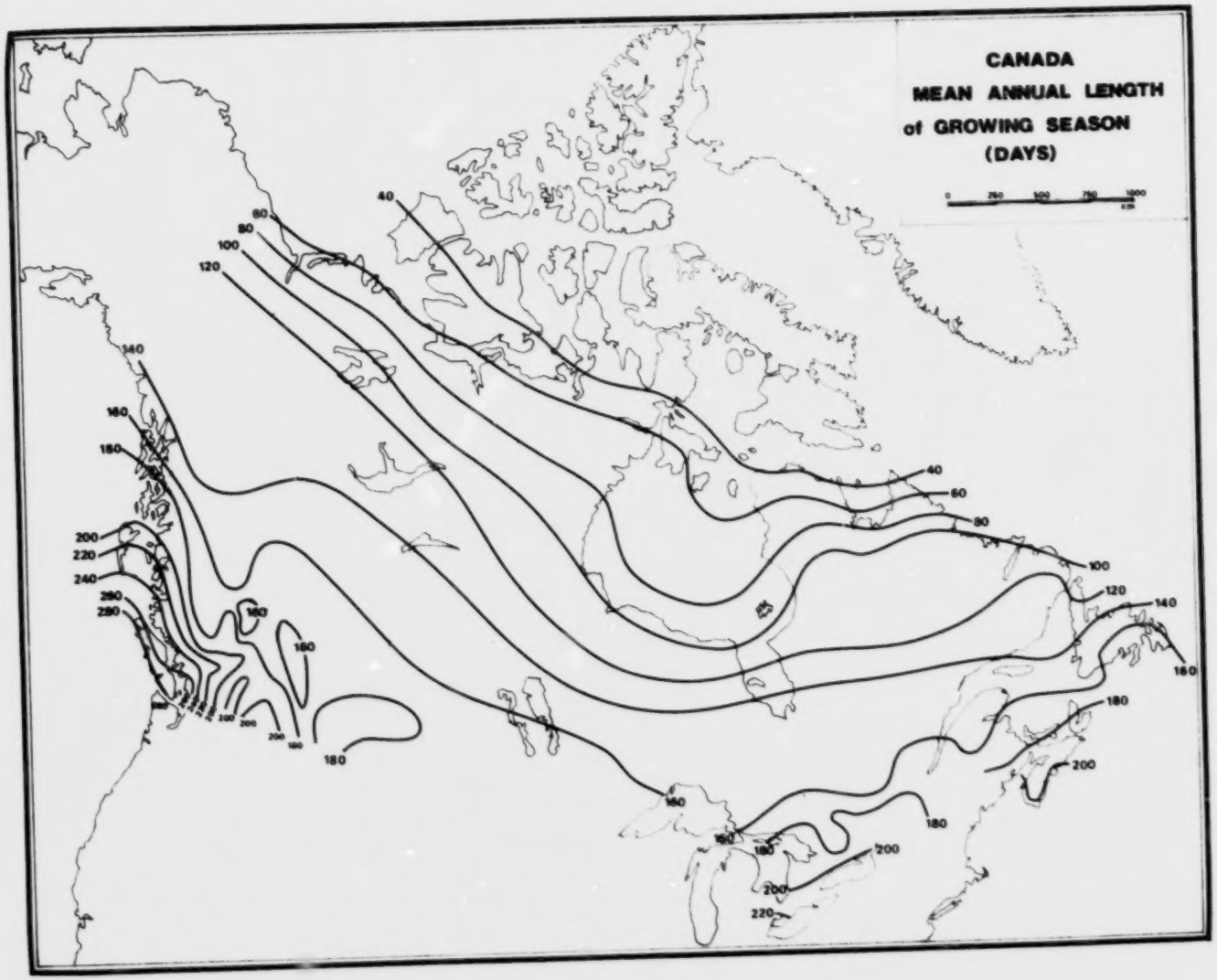

Figure 2. Temperature-related isolines paralleling the northwest-southeast trend of the Boreal Forest Region in Canada (Rowe 1972).

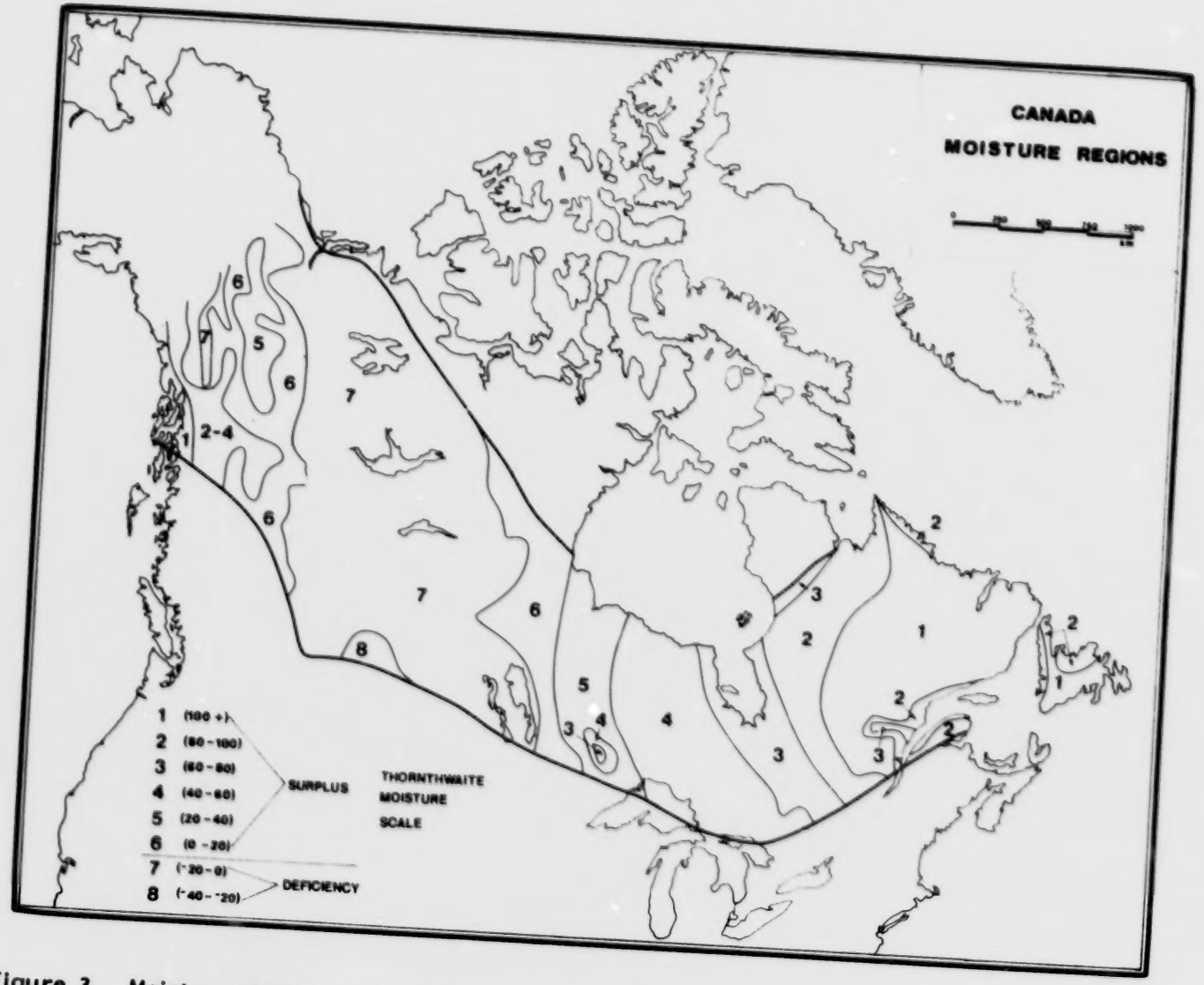

Figure 3. Moisture-related isolines perpendicular to the northwest-southeast trend of the Boreal Forest Region in Canada (Rowe 1972).

(Figure 4), at least in the portion of the boreal zone west of Hudson Bay (Bryson 1966). There have also been many attempts to simplify climate/growth relationships by use of predictive equations such as those developed by Lieth (1978), Tukhanen (1980), and Walter (1968). All of these approaches deal with climate on a macroscale, but there is increasing evidence that real relationships between vegetation and radiation, temperature, humidity, precipitation or wind must be examined at mesoscale and microscale levels (Larsen 1980).

Most early attempts to relate climate to plant productivity assumed that forest production increases linearly with rising mean temperatures for the warmest month, increasing precipitation, and lengthening of the growing season and that it declines with distance from the equator. Regressions by Lieth (1978) show these general relationships between net primary productivity, temperature, and precipitation (Figure 5). Recent studies have brought these earlier assumptions into question. Under conditions of sufficient moisture, primary production is known to be most affected by two factors - photosynthetically active radiation (0.38 to 0.71 micron wavelengths) and temperature (Budyko 1974). The most reliable predictions of net primary production appear to be provided by the index developed by Budyko and co-workers:

Capacity for net primary production

$$= \frac{R}{Lr}$$

where R = total incoming annual solar radiation (kcal/cm^2/yr)

and Lr = the amount of heat necessary to evaporate the annual precipitation (the radiative index of dryness), with L = annual precipitation (cm) and r = latent heat of water calculated at 540 cal/ml.

According to Budyko's predictive equation, the heat factor operates in a single direction, with plant productivity increasing as the value of R rises. The rate of plant growth, however, tends to vary for different values of R within the dryness index interval of 0.4 to 1.4. At low values of R, the addition of heat produces a rapid relative increase of primary production but in a warm situation the same heat increment produces a smaller relative increase in growth. At values of the radiation balance below 40 kcal/cm^2/yr, productivity increases rapidly with the additional application of heat. At higher values of R (above 50 kcal/cm^2/yr), moisture is the predominant factor in increasing plant productivity; this is especially noticeable as the dryness index declines below 1 (Drozdov 1971). The capacity for net primary production, estimated from the variables listed in Budyko's equation above, has been determined and mapped by Rodin et al. (1975) for the boreal zone in Canada (Figure 6) and by Budyko (1974) for the boreal zone in the U.S.S.R. (Figure 7). A climate-productivity diagram prepared by Walter (1968) summarizes the position of the boreal forest, along with other major vegetation zones in

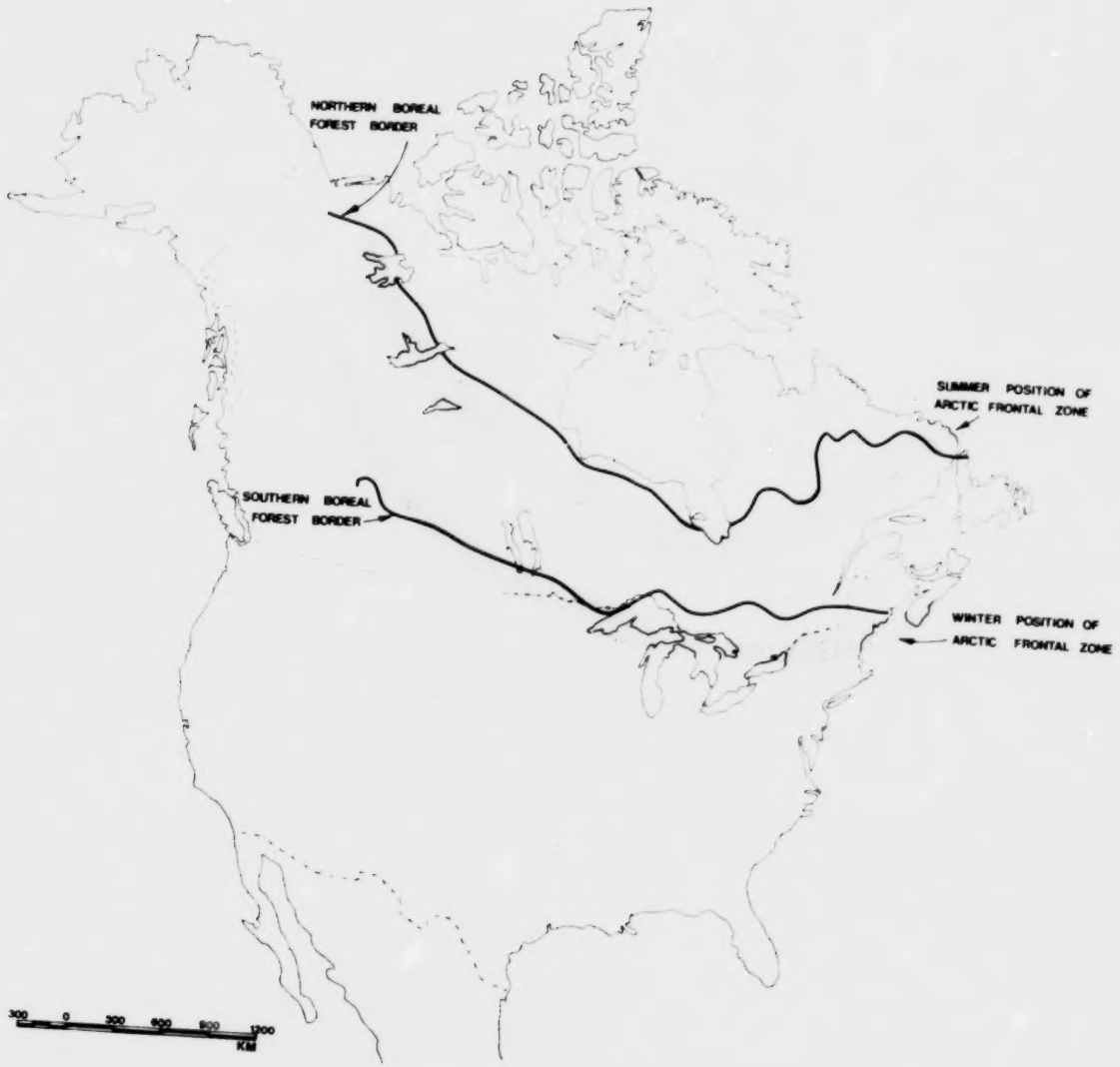

Figure 4. Coincidence of boreal forest boundaries and air-mass boundaries in the present climate (Bryson 1966).

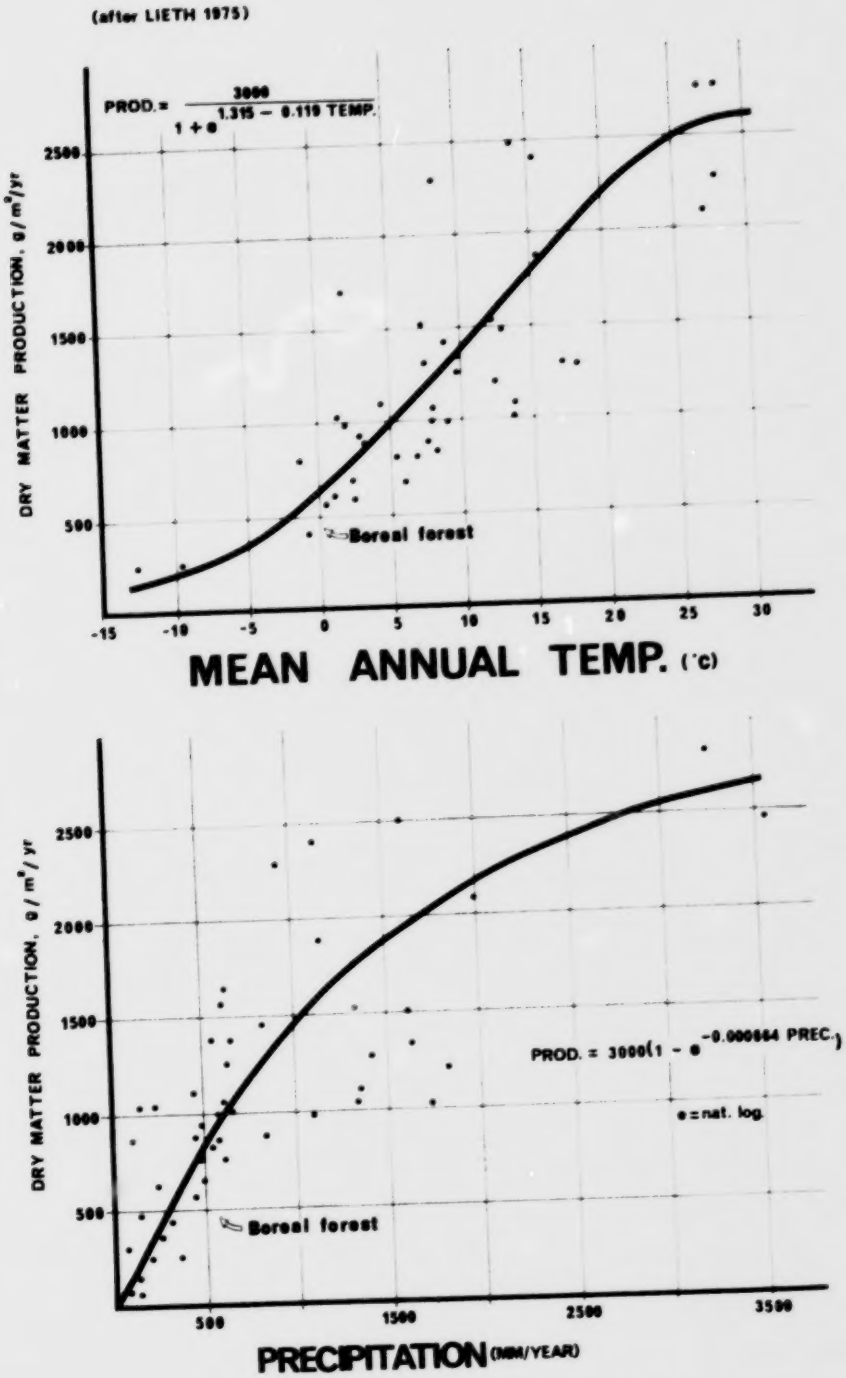

Figure 5. Net primary productivity ($g/m^2/yr$) in relation to mean annual temperature (°C) and mean annual precipitation (mm/yr) (Lieth 1975).

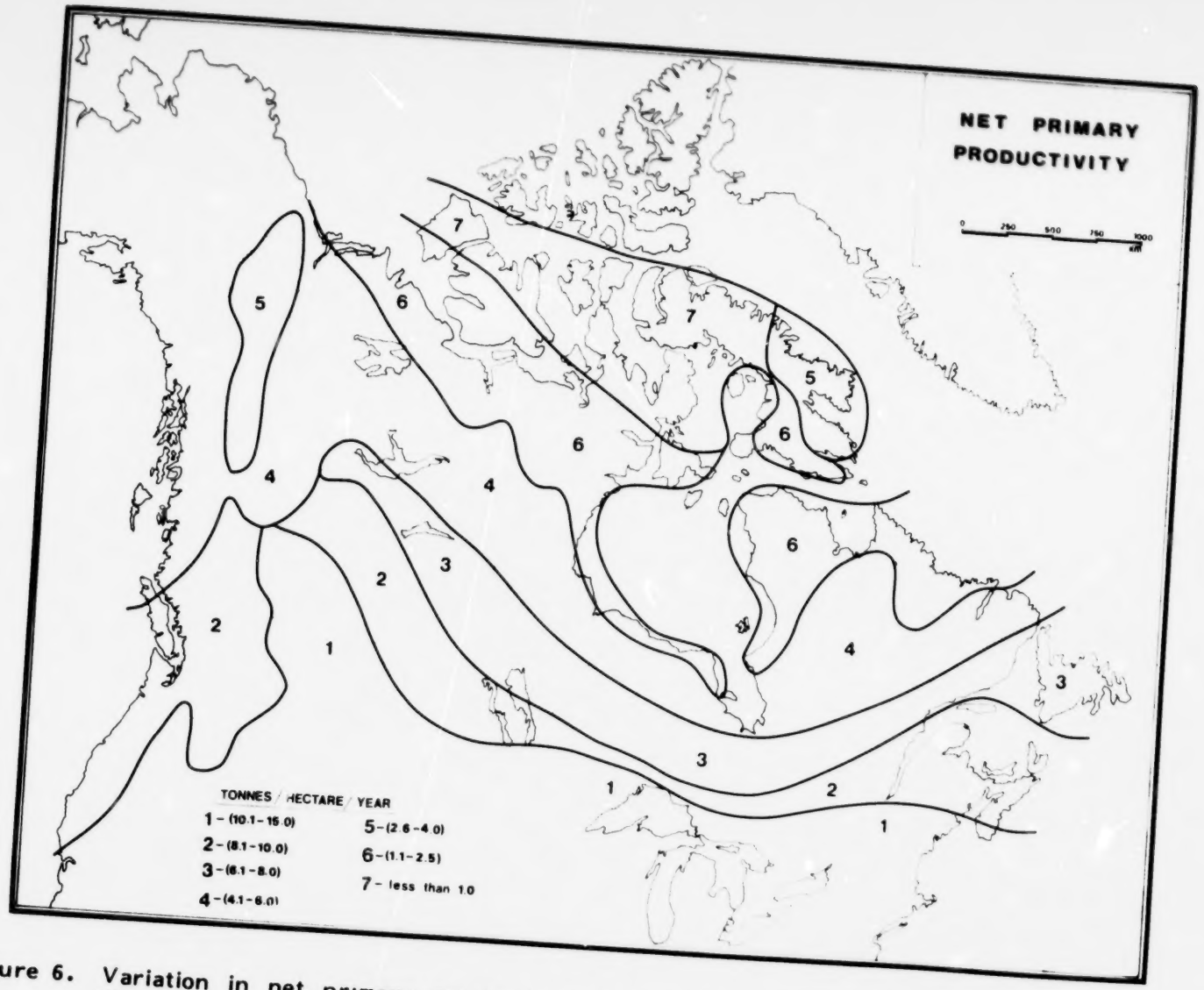

Figure 6. Variation in net primary productivity (t/ha/yr) within the Canadian Boreal Forest Region (Rodin et al. 1975).

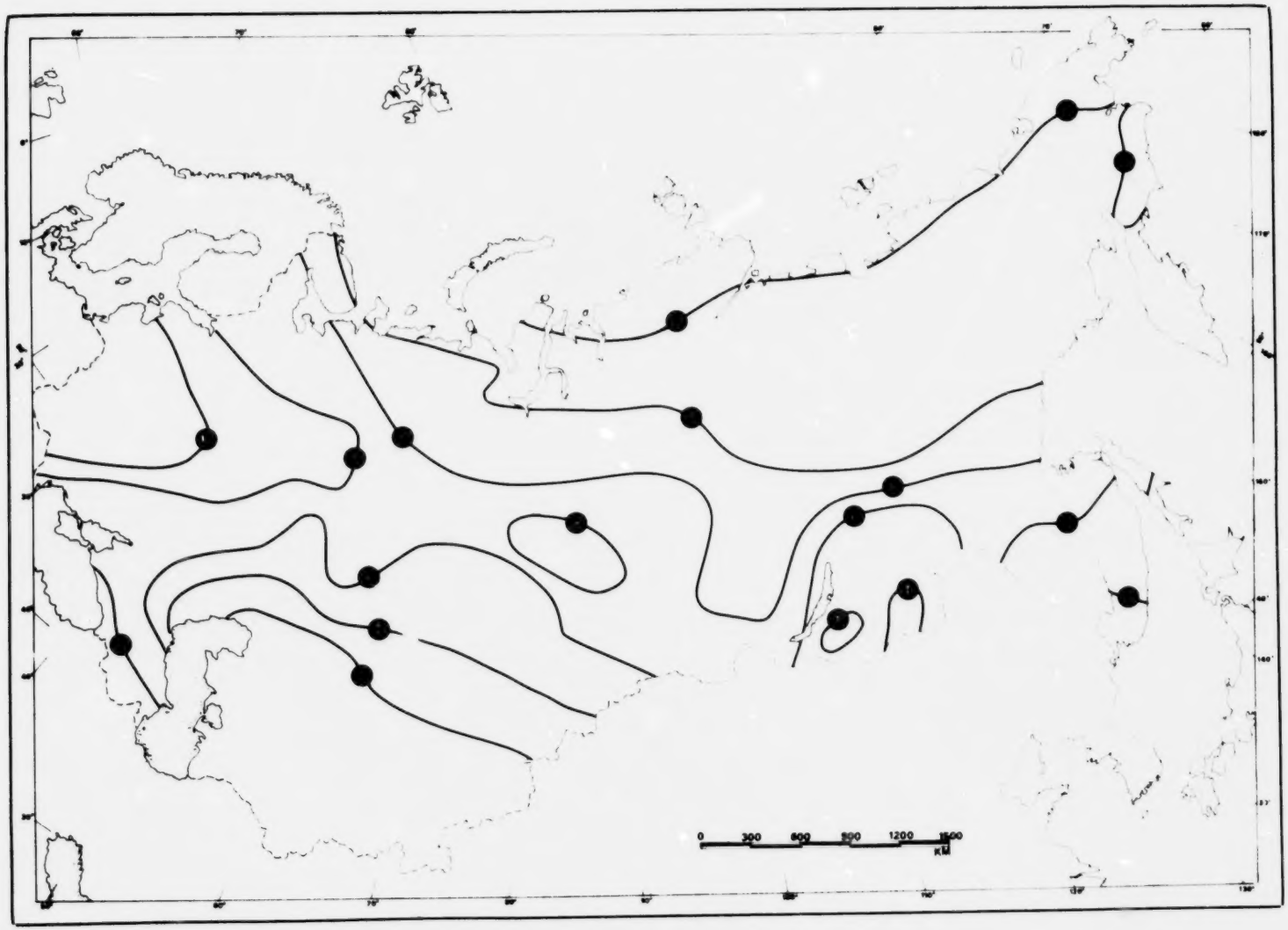

Figure 7. Variation in net primary productivity (t/ha/yr) within the U.S.S.R. Boreal Forest Region (Budyko 1974).

a north-south transect from tundra to semidesert in the east European lowlands, in relation to gradients of annual evaporation, growing season, solar radiation, mean annual temperature and mean annual precipitation (Figure 8).

The references reviewed in this bibliography revealed a relatively large number of climatic variables that have an influence on boreal net primary productivity or biomass accumulation. Literature sources that suggest either an increase or a decrease in biomass accumulation as a result of an assumed change in specific climatic variables are identified in Table 1. The identified relationships between climate and net primary productivity can serve as hypotheses on the likely positive or negative impact on boreal biomass accumulation when there is reason to suspect a given change in some climatic variable. It is evident from Table 1 that temperature-related parameters dominate over moisture and other climatic variables as determinants of net primary productivity in boreal forest regions.

Patterns of global temperature change are not well documented yet. From paleoclimatic studies there is evidence that some atmospheric disturbance that influences temperature, particularly winter temperature, makes steady progress westward around the northern hemisphere, completing one circuit in about 600 years (Lamb 1977). On a shorter time scale, air temperatures over most of the globe reached their directly recorded maxima in about the early 1940s, toward the end of several decades of relatively strong atmospheric circulation; the subsequent fall of temperature to the levels maintained from 1965 to 1975 is thought to be the longest continued downward temperature trend since 1700 (Lamb 1977). These trends are of importance in the boreal forest zone, which lies in a latitudinal belt where temperature changes tend to be amplified. For example, surface temperature anomalies in the northern hemisphere following the dust veils produced by volcanoes between 1952 and 1970 were in all cases greater at high latitudes (50-90° N) than they were south of 50° N, regardless of where the eruption occurred (Lamb 1977).

2.2 Nonclimatic Factors or Processes that Influence Boreal Biomass Accumulation Rates

The literature documents a relatively large number of factors other than climate that control net primary productivity and biomass accumulation in boreal forest ecosystems. Such factors or processes are summarized in Table 2 under two headings: nonclimatic factors that influence forest growth independently of climate and nonclimatic factors that may be indirectly triggered or regulated by climatic events. Several distinctive features of boreal forest ecosystems influence their capacity for biomass accumulation. As summarized below, there is evidence in the literature that inherent ecosystem features or processes often override the influences of climatic factors upon net primary productivity of boreal forest vegetation.

(after WALTER 1968)

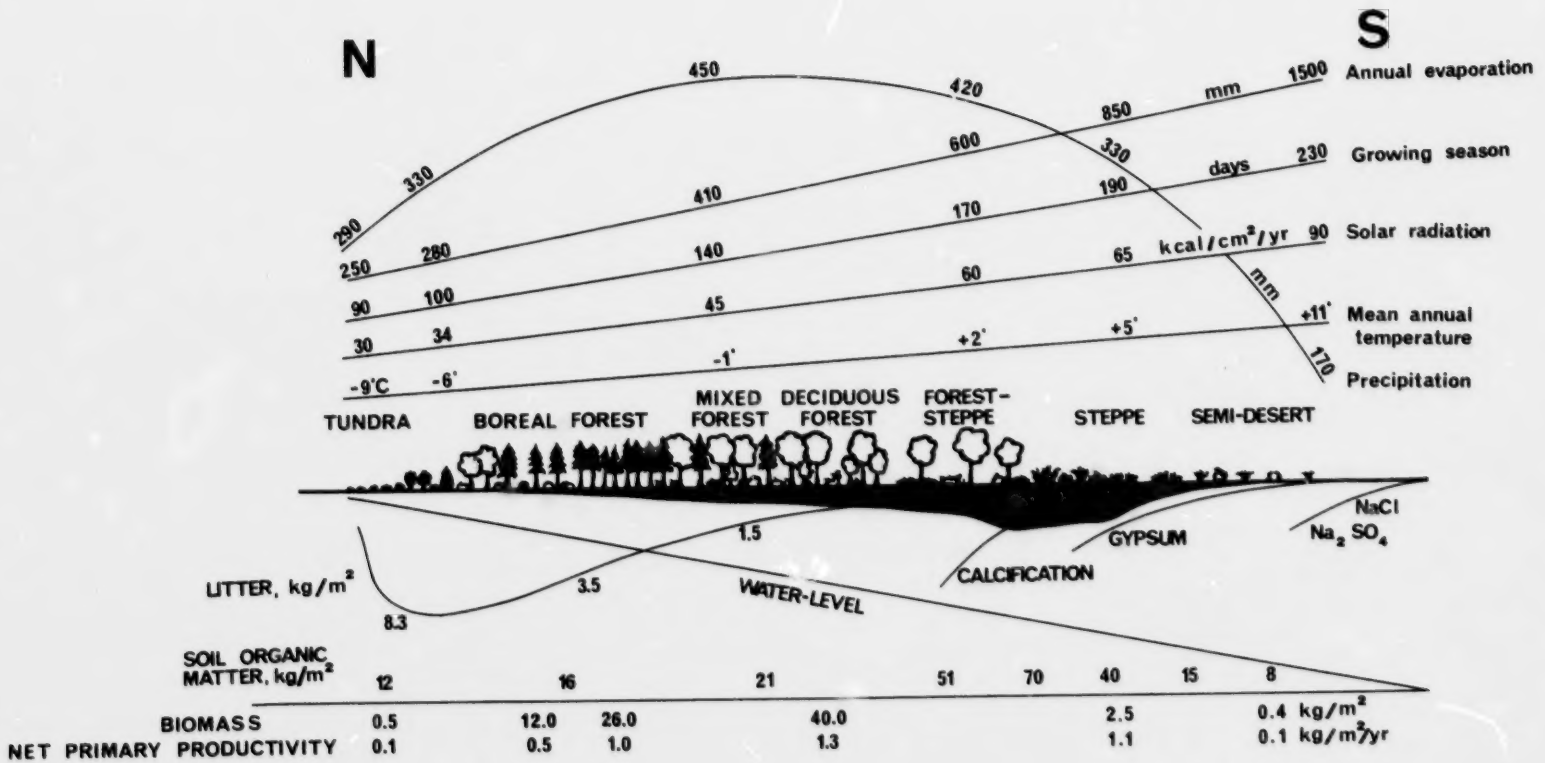

Figure 8. Biomass (kg/m^2) and net primary production ($kg/m^2/yr$) in relation to evaporation, growing season, solar radiation, mean annual temperature, and mean annual precipitation in a north-south transect from tundra to semidesert in the east European lowlands (Walter 1968).

TABLE 1

CLIMATIC FACTORS OR PROCESSES THAT INFLUENCE

BIOMASS ACCUMULATION RATES IN BOREAL FOREST ECOSYSTEMS

ASSUMED CHANGE IN FACTOR OR PROCESS	CHANGE IN NET PRIMARY PRODUCTION INCREASE	DECREASE	REPRESENTATIVE REFERENCE SOURCE
TEMPERATURE FACTORS			
Increased mean summer temperature	*		Viereck 1979
Increased degree-days over 10°C for June & July	*		Jacoby & Cook 1981
Increased annual actual evapotranspiration	*		Rosenzweig 1968
Increased potential evapotranspiration	*		Rosenzwieg 1968
Increased mean annual temperature	*		Lieth 1974
Increased degree-days over 0°C	*		Black & Bliss 1980
Increased growing degree-days in frost-free season	*		Boughner 1964
Increased temperature of warmest part of day	*		Bray 1971
Increased temperature during growing season	*		Adamenko 1963
Increased Thornthwaite thermal efficiency	*		Ahti 1961
Increased July temperature of current year	*		Andrews et al 1981
Increased length of frost-free season	*		Christie & Lines 1979
Lower temperature previous July, August, & October	*		Conkey 1979
Higher temperatures previous December & January	*		Conkey 1979
Higher temperatures in May, July, & September of current growing season	*		Conkey 1979
Increased mean temperature of warmest month (Paterson's CVP index)	*		Lemieux 1961
Increased cumulative summer warmth, measured as degree-days above 50°F	*		Ritchie & Hare 1971
Increased mean temperature in April of year preceding present growing season	*		Shpalte 1978
Decreased mean temperature in April of present growing season	*		Jacoby & Ulan 1981
Increased mean temperature in March of the current growing season	*		Shpalte 1978
Increased temperature sum, measured by the summation of the mean temperatures of all days with a mean temperature above 5°C	*		Sarvas 1970
Increased mean temperature of the growing season	*		Giddings 1943
Increased temperature in prior & concurrent June	*		Cropper & Fritts 1981
Increased previous autumn temperature	*		Garfinkel & Brubaker 1980
Deepening active layer	*		Sakai et al 1979
Lower cold-season temperature as a limiting factor for insect abundance	*		Nicholson & Bryant 1972
Increased variance in summer temperature during periods of meridional circulation		*	Lamb 1977
Greater occurrence of temperature extremes during growing season		*	Boughner 1964
Deviation from optimum ratio of temperature and precipitation		*	Bazilevich et al 1971
Increased difference between the mean temperatures of the warmest and coldest months (Paterson's CVP index)		*	Lemieux 1961
Increased temperature in prior August		*	Cropper & Fritts 1981
Increased winter-early spring temperature		*	Garfinkel & Brubaker 1980
Increased plant stress due to warm air temperatures while soil is frozen		*	Giddings 1962

Continued ....

TABLE 1 (Continued)

ASSUMED CHANGE IN FACTOR OR PROCESS	CHANGE IN NET PRIMARY PRODUCTION INCREASE	DECREASE	REPRESENTATIVE REFERENCE SOURCE
INSOLATION AND RADIATION FACTORS			
Increased length of photosynthetic period	•		Lieth 1975
Increased solar radiation	•		Kay 1976
Increased radiation balance for a given set of moisture conditions	•		Budyko 1974
Increased hours of sunlight	•		Beattie et al 1981
Increased day length	•		Christie & Lines 1979
Increased light intensity during growing season	•		Vowinckel et al 1975
Increased levels of photosynthetically active radiation (0.38-0.71 micron wavelengths) during growing season	•		Yefimova 1971
Optimal ratio of radiation & aridity index	•		Drozdov 1971
Increased mean yearly number of sunspots	•		Bray 1965
Increased solar activity	•		Bray 1971
Lowered earth's albedo & more heat absorbed		•	Bach 1979
Increased winter albedo		•	Bray 1971
PRECIPITATION FACTORS			
Increased mean annual precipitation	•		Lieth 1974
Increased moisture for a given radiation balance	•		Budyko 1974
Increased rainfall frequency in relation to growth of mosses	•		Busby et al 1978
Increased moisture availability during growing season	•		Christie & Lines 1979
Increased humidity (Paterson's CVP index)	•		Lemieux 1961
Increased precipitation previous year	•		Conkey 1979
Increased precipitation prior June & November	•		Cropper & Fritts 1981
Increased snow cover for winter insulation of shrubs	•		Hare & Ritchie 1972
Increased July rainfall	•		Høeg 1956
Above average August precipitation	•		Jacoby & Ulan 1981
Increased ratio of annual effective precipitation times duration of growing season over average annual radiation balance	•		Rodin et al 1975
Shortened growing season as a result of late snow cover		•	Laaksonen 1979
Increased moisture stress		•	Black & Bliss 1980
Deviation from optimum balance between evaporation ratio & water transport in relation to growth of mosses		•	Busby et al 1978
Increased paludification due to cool humid conditions		•	Dionne 1979
Increased snow, hail, & ice glaze damage to tree limbs		•	Bakuzis & Hansen 1965
AIR MASS, ATMOSPHERIC, AND WIND FACTORS			
Man-caused increases of atmospheric CO_2 as a moderating influence of natural global cooling since 1950	•		Lamb & Mörth 1978
Increased zonal atmospheric circulation	•		Pohtila 1980
Reduction of atmospheric transmittance as a result of volcanic dust		•	Bryson 1974
Increased summer frontal activity resulting in increased cloudiness, which reduces photosynthesis		•	Kay 1976
Advection of cold air from nearby cold seas in summer		•	Laaksonen 1979
Increased atmospheric CO_2, which increases global temperature to harmful levels		•	Allen 1980
Increased abrasion to trees by wind-borne snow & ice		•	Black & Bliss 1980
Increased winds that increase incidence of windthrow in trees		•	Christie & Lines 1979
Increased amounts of cloud		•	Hare & Ritchie 1972

TABLE 2

NON-CLIMATIC FACTORS OR PROCESSES THAT INFLUENCE

BIOMASS ACCUMULATION RATES IN BOREAL FOREST ECOSYSTEMS

ASSUMED CHANGE IN FACTOR OR PROCESS	CHANGE IN NET PRIMARY PRODUCTION: INCREASE	DECREASE	REPRESENTATIVE REFERENCE SOURCE
NONCLIMATIC FACTORS THAT ACT INDEPENDENTLY OF CLIMATE			
Increased organic matter turnover rates and larger annual fluxes of nutrients if disturbance leads to dominance by deciduous tree species (aspen & birch)	•		Zasada et al 1977
Increased leaf area index (surface area of leaves per unit area of land) as one progresses northward within boreal zone	•		Jones 1979
Increased amounts of foliage in trees	•		Doucet et al 1976
Peatlands with mineral soil islands have more productive forests downslope of the islands because of addition of nutrients to groundwater as it passes through the mineral soils	•		Larsen 1980
Increased stand density	•		Baskerville 1965
Increased canopy closure	•		Hare & Thomas 1974
Improved soil drainage	•		Bellefleur & Auclair 1972
Increased soil moisture	•		Bray & Dudkiewicz 1963
Disturbances that lead to young successional stages	•		Lieth 1974
Increased potential for tree growth as a result of better adapted genotypes	•		Christie & Lines 1979
Loss of nutrients during deforestation		•	Ajtay et al 1979
Successional development of muskeg conditions		•	Van Cleve et al 1981
Declining soil temperature as a result of thickened moss layer in late stages of succession		•	Zasada et al 1977
Post-glacial altitudinal rebound of land surfaces		•	Karlen 1976
Reduced soil aeration as a result of excess water in poorly drained sites		•	Payandeh 1973
Intraspecfic competition amongst trees		•	Black & Bliss 1980
Decreased soil nutrients		•	Bray& Dudkiewicz 1963
Depletion of soil nutrients due to their accumulation in forest floor biomass		•	Zasada et al 1977
Removal of tree canopy as a factor in primary production by mosses		•	Busby et al 1978
NONCLIMATIC FACTORS THAT MAY BE TRIGGERED BY CLIMATIC CONDITIONS			
Postfire recycling of nutrients formerly bound in standing crop and in forest floor	•		Wright & Heinselman 1973
Postfire warming of soil & increase of active layer depth	•		Van Cleve & Viereck 1981
Increased lichen productivity in successional stages after fire	•		Ahti 1977
Postfire development of herb/shrub layers	•		Johnson & Rowe 1977
Floodplain deposition of silt (addition of nutrients & burying of insulative forest floor)	•		Zasada et al 1977
Increased inputs of seepage water	•		Høeg 1956
Low level insect defoliation	•		Mattson & Addy 1975
Removal of biomass by fire		•	Ahti 1977
Acceleration of paludification as a result of long-term exclusion of fire		•	Heinselman 1981
Removal of biomass by flooding		•	Borisov 1965
Flooding that limits root growth and thereby reduces ability of trees to absorb water		•	Stockton & Fritts 1973
Increased rate of respiration without an accompanying increase in photosynthesis		•	Bray & Gorham 1964
Increased frequency of population peaks of defoliating insects		•	Grison 1971
Shortening of rotation age, which increases influence of diseases on primary production because of insufficient time for enhanced growth of survivors		•	Pollard 1971

A south to north cross-section of the boreal forest shows a decline in prominence of deciduous trees, an increase in the proportion of conifers, and a decrease in tree heights (Rowe and Scotter 1973). It has been suggested that one reason for the success of conifers in the climatically harsh boreal zone is their relatively high leaf area index. In the southern part of the boreal zone, leaf area index may reach 9 m^2 of leaf surface area per square metre of land surface; at the northern limits of the zone, leaf area index may reach the exceptionally high value of 11 m^2/m^2 (Jones 1979). With lower available solar radiation, conifers have an advantage over deciduous species (Jordan 1971), and this explains why conifers replace deciduous species along a gradient of decreasing solar radiation from the tropics to the boreal zone, or with increasing altitude in mountains.

Reduced activity of forest insects and diseases as one progresses northward within the boreal zone results in relatively great ages of individual trees near the northern limits of the zone, if the growing site is protected from fire. Most boreal stands are less than 100 years old, however, because of recurring periods of high fire frequency (Rowe and Scotter 1973). There is growing evidence that boreal ecosystems are "disaster-adapted," with the most likely disturbances being natural fires, severe windstorms, soil erosion or flooding (Heinselman 1981, Ritchie 1980). Normal insect grazing, involving 5-30% of annual foliage crops, usually does not impair annual primary production. In fact, such grazing may accelerate growth (Mattson and Addy 1975). For example, there is evidence that aspen stands defoliated for 2 or 3 years may actually show larger height growth and slightly more diameter growth than before defoliation. Wood production may increase after severe defoliations because the circulation of nitrogen, phosphorus, and potassium is enhanced or because the distribution of light and moisture is more equitably available to trees in the stand (Mattson and Addy 1975).

Boreal forest productivity is strongly related to topography. The most productive sites tend to occur on southern aspects where soils are warmer; less productive ecosystems occur on the cold soils of lowland sites. Topographic sequences from warm, dry sites that are free from permafrost to wet, permafrost-dominated sites correspond to a gradient from high to low ecosystem productivity. In addition to such topographic controls, the availability of nitrogen is generally believed to be a key factor limiting growth on many boreal sites (Zasada et al. 1977). It has also been observed that there is a narrowing of average growth rates as one progresses northward through the boreal forest; at the northern forest border, the rate of growth on optimum sites does not greatly exceed the rate on the poorest sites (Larsen 1980).

With time, complete structural changes may take place in lowland sites within the boreal zone where

forested sites may change to peat-dominated wetland sites through a process of paludification, often as a result of cooler and more humid conditions (Dionne 1979). In untreed boreal peatland, biomass of live stems beneath the peatland surface has been recorded to be as much as 4.6 times the value of aerial biomass; such subsurface production of woody biomass is partly a result of the development of new adventitious roots as aerial stems are buried by accumulating peat (Larsen 1980).

The characteristically large accumulation of biomass on the floor of mature boreal forest stands has an important influence on productivity. In the absence of fire, boreal forests continue to accumulate biomass on the forest floor. This mossy layer is an effective insulation that reduces mineral soil temperature and hence site productivity. There is also an accompanying reduction in soil nutrients because of accumulation of nutrients in the forest floor biomass (Zasada et al. 1977).

Black spruce forests have a high level of moss production compared to other forest types; annual net primary production in the moss layer of black spruce stands may be as great as 120 $g/m^2/yr$, nearly as much as in the tree layer. In general, the depth of organic matter on the forest floor is greatest in those ecosystems that display the lowest tree production. Balsam poplar, birch, and white spruce may produce four to seven times more tree biomass above ground than black spruce in a given time period (Van Cleve et al. 1979).

In uplands, black spruce ecosystems typify the slowest nutrient cycling rates, a factor related to low productivity. White spruce, birch, and aspen display higher rates of productivity and nutrient cycling than black spruce stands. Birch and aspen, in turn, display up to threefold higher forest floor organic matter turnover rates than white spruce. A large annual flux of nutrients occurs in the forest floor beneath deciduous trees where all leaves are shed each autumn, whereas foliage can be retained on black spruce trees for up to 25 years. Longer foliage retention and slower forest floor decomposition rates characterize ecosystems that are more nutrient conservative. Following fire, black spruce ecosystems initially have the potential productivity and rates of nutrient cycling characteristic of warmer, more productive aspen, birch or white spruce ecosystems. During postfire succession, however, black spruce stands gradually revert to lower productivity and reduced rates of nutrient cycling (Van Cleve and Viereck 1981, Zasada et al. 1977).

Studies in Alaska have indicated that forest ecosystems on alluvial sites are less conservative with respect to nutrient loss than are upland sites, especially in younger stages of succession. Balsam poplar, alder, and willow are the most productive floodplain ecosystems and display the most rapid cycling of nutrients in the boreal zone (Zasada et al. 1977).

As pointed out by Ajtay et al. (1979), an important characteristic of boreal ecosystems is the large

proportion of total ecosystem organic matter that is in the soil (Figure 9). In Alaskan black spruce ecosystems, there is up to 10 times more organic matter in the mineral soil, below the forest floor, than there is in the tree layer (Van Cleve et al. 1981). This large pool of below-ground carbon has a potentially important stabilizing influence upon atmospheric levels of CO_2. Even if climatic changes were large on a local or regional scale, atmospheric CO_2, on a biospheric scale, would change comparatively slowly because of the relative stability provided by carbon pools in the oceans and in northern soils that have a high carbon content (Bolin 1980).

In summary, an outstanding feature of boreal forest ecosystems is the prominence of the forest floor and forest soil as a major nutrient and carbon pool. The reserves of nutrients in organic surface layers are in many instances several times larger than the amounts contained in the standing tree biomass of middle-aged and mature forest stands. The rates of nutrient cycling and associated site fertility are thus closely related to biological controls of forest floor decomposition and accumulation. Man-made improvements to the generally low productivity in boreal forest ecosystems cannot be achieved without measures that involve control of forest floor processes (Krause et al. 1978).

2.3 Influence of Boreal Biomass Burning on Atmospheric CO_2 Levels

It is well established that the CO_2 content of the atmosphere is increasing. Data from Hawaii, the South Pole, and the upper troposphere of the northern hemisphere are available for almost 20 years. The increase has been about 16 parts per million (ppm) - from 311 ppm in 1957 to 327 ppm in 1975 - that is, about 5% (Bolin 1977). The amount of reduction of forest cover in this 20-year period is the subject of some controversy (Seiler and Crutzen 1980). Bolin (1977), however, has estimated that in the 20 years that have seen such a marked increase in atmospheric CO_2, the net loss in forest cover in developed countries is probably less than 1%, which is insignificant in relation to the large CO_2 changes. Bolin's estimates indicate that, in the developing countries as a whole, about 0.12×10^6 km^2 of natural forest is cleared and burned every year. It is estimated that the areas of closed forests in the developing countries will have decreased by 20-25% by the turn of the century if this trend continues. If one assumes that all of the biomass in these forests burns (20 kg of carbon per square metre), there would be an annual input of 1.5×10^9 t of carbon into the atmosphere in the form of CO_2. This is likely to be an overestimate, partly because not all of the living biomass burns and partly because some of these areas again become covered by vegetation, although usually not forests (Bolin 1977). Some investigators have

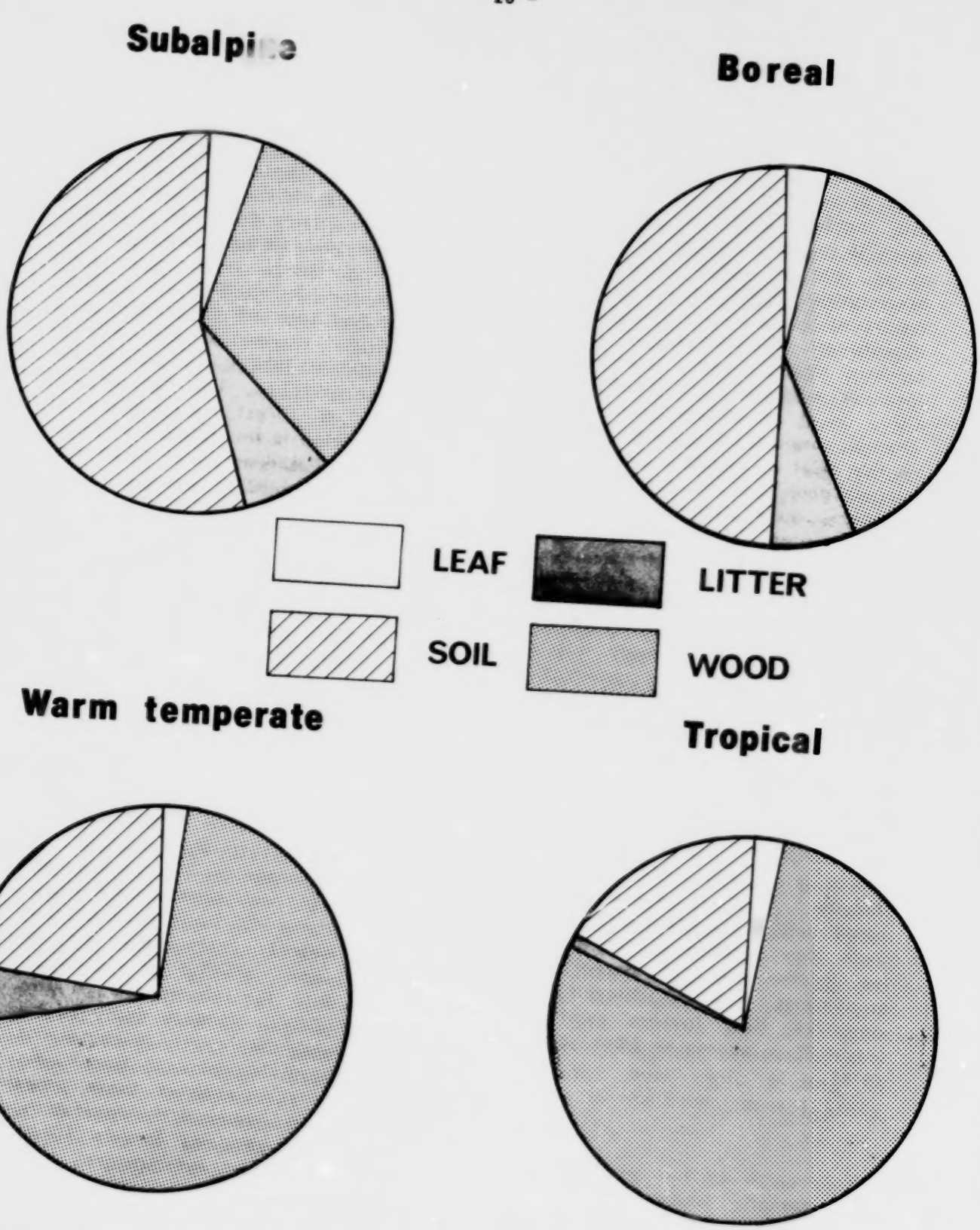

Figure 9. Partitioning of organic carbon in different climatic zones (Ajtay et al. 1979).

suggested that the decay of soil organic matter, rather than burning of aboveground biomass, appears to be one of the largest CO_2 inputs to the atmosphere (Bramryd 1979).

Contrary to the above opinions is the view that biomass burning is a significant contributor to atmospheric CO_2 levels. The atmospheric input of CO_2 from burning wood, in particular from natural and man-made forest fires in boreal, temperate, and tropical regions, has been estimated to be 5.7×10^{15} g of carbon per year as gross input and 1.5×10^{15} g of carbon per year as net input. This is a significant amount when compared to the CO_2 produced from the utilization of oil, gas, coal, and limestone (Wong 1978).

The largest amount of biomass per unit area of land is found in the tropical forests, with an average aboveground dry matter value of 39 kg/m^2, followed by 35 kg/m^2 for temperate forests and 25 kg/m^2 for boreal forests (Seiler and Crutzen 1980). Wildfires are common in boreal forests. Statistical data on burned areas in these forests are available only for Canada, where on the average about 0.4×10^6 ha, or 0.1% of the standing boreal forest, are destroyed annually by fires, mainly during springtime. Fire statistics for the Asian continent are lacking, but it is likely that the burning rates in these areas are comparable to those observed in Canada. Based on a total area of 12×10^6 km^2 for boreal forests, the annually burned area accounts for $1.0\text{-}1.5 \times 10^6$ ha, containing a total biomass of 250 to 375 Tg of dry matter (1 Tg = 1 teragram = 10^{12} grams). With an average aboveground biomass fraction of 73% and a burning efficiency of 20%, as found in temperate forests, the burned biomass in boreal forests has been estimated to be 37-55 Tg of dry matter per year (Seiler and Crutzen 1980). There is, however, debate over the estimates of burning efficiency (Fahnestock 1979, Wong 1979).

For wildfires in boreal forests, Seiler and Crutzen (1980) presented the following summary data, with the range shown for each variable:

Annually burned and/or cleared area, 1.0-1.5 million ha

Total biomass cleared annually, 250-380 Tg dry matter*

Biomass annually exposed to fire, 180-270 Tg dry matter

Annually burned biomass, 40-60 Tg dry matter

Dead belowground biomass in boreal forests, 70-110 Tg dry matter

Dead unburned aboveground biomass in boreal forests, 140-210 Tg dry matter

* To convert dry matter to carbon, multiply by 0.45.

As shown by the data summarized above, a considerable part of the biomass exposed to fire remains unburned in the field, mainly as dead organic matter and charcoal. Whereas

the dead organic matter is gradually decomposed by microbial activity, the charcoal cannot be metabolized in significant amounts by microorganisms and therefore remains in the soil for a long time. Most calculations of atmospheric CO_2 releases have so far been based on the assumption that the carbon in biomass that is cleared by deforestation is directly released into the atmosphere as CO_2. Observations by some researchers, however, indicate that this is not the case. It is known that approximately 30% of the total biomass is stored in the roots of plants and that this is only partly attacked by fire. Furthermore, only part of the biomass exposed to fires is actually burned. The rest remains as unburned organic matter or as charcoal (graphitic carbon). Because graphitic carbon cannot readily be utilized by microorganisms, the formation of charcoal is equivalent to a sink for atmospheric CO_2 and a source of O_2 (Seiler and Crutzen 1980).

There is contradictory evidence as to whether the land biota is a net source or a net sink of carbon for the atmosphere (Chan 1978). Because of these differences of opinion, Hampicke (1979) urged more detailed study of three possible carbon sinks: a net growth of temperate forests, the delayed decomposition of organic material in the boreal zone, and the transportation of organic and inorganic carbon into the sea by rivers. Hampicke (1979) assumed that the presently unexplained carbon sinks must be on land rather than in the ocean. The "detritus" pool has not been thoroughly investigated, especially peat accumulation, incomplete litter decompostion in the boreal zone, removal of terrestrial humus by rivers, and removal of respiratory CO_2 by groundwater and rivers. It is estimated that these potential, but undocumented, carbon sinks might together account for an annual withdrawal in the order of 1×10^{15} g of carbon.

Other poorly known parameters in relation to the effects of biomass burning are the total land area burned annually and the burning efficiencies of the biomass in individual ecosystems. The average phytomass per unit area and the fraction of the aboveground biomass in individual ecosystems are better known but nevertheless still uncertain (Seiler and Crutzen 1980). Other researchers have stressed that it is important to obtain more data on the combustion efficiency of forest wood, a highly variable quantity between 0.20 and 0.75. This variable is affected by such environmental factors as the intensity of heat, humidity, wind, the duration of burning, and the nature of woody material. The charred remains of unburned wood may eventually decay and add CO_2 to the atmospheric CO_2 reservoir, but this process is also difficult to quantify. Dead standing trees left by a fire decompose more quickly than fallen logs (D.F.W. Pollard, pers. comm. by letter, 1982) and variability in the relative amounts of fire-killed timber that remains standing and that falls to the ground after a fire adds to the difficulty of estimating rates by which carbon is released from boreal forests after

fires. Uncertainties in assessing other land carbon sources also make it difficult to quantify the carbon cycle (Wong 1979). The most serious lack of knowledge in the carbon cycle is in the detritus reservoirs of dead carbon, both on land and in the marine environment. The total detritus standing mass is estimated to be 3×10^{18} g of carbon, thought to be approximately equally distributed on land and in the ocean, but the amounts are not known (Wong 1978).

In addition to its influence on CO_2 levels, it appears that biomass burning, especially in the tropics where the rates of net primary production and biomass burning are high, has the potential to contribute to the global budgets of several major atmospheric trace gases. Another reason why the tropics are more significant than boreal areas in this regard relates to the fact that emissions released in the tropics occur in a photochemically very active and dynamically important region, in which substantial transfers of tropospheric air to the stratosphere take place (Crutzen et al. 1979).

2.4 Overview of Boreal Climate-Biomass Relationships

2.4.1 Climatic change and climatic variability

The voluminous literature on climatic change has been expressed in terms of many different variables. Two themes dominate when climatic change is viewed in relation to boreal forest growth; one focusses on cyclic and noncyclic **temperature changes** and the other refers to an increase in the **variability of weather**. Cyclic climatic changes associated with variations in solar activity and noncyclic changes associated with the influence of volcanic dust upon atmospheric transmittance appear to be the dominant causes of temperature shifts in the northern hemisphere over the past few hundred years.

Almost all efforts to identify a sun-weather connection have concentrated on short-term changes, focussing on the cyclic behavior of solar activity. The latter is most easily observed as daily changes in the numbers of spots on the sun or as the 11-year sunspot cycle. The existence of longer-term changes is apparent in the sunspot record that extends back for over 350 years, embracing periods of marked terrestrial climate change. The amplitudes achieved at 11-year maxima in the curve of annual sunspot numbers are far from uniform. There is an apparent 80-year cycle, called the 'Gleissberg cycle', and other longer-term anomalies. The persistent rise in the level of solar activity in the first half of the present century matches very well with the established increase in world temperature averages during the same time (Eddy 1977).

Since the climate is primarily determined by processes near the earth's surface, the solar energy arriving at the top of the atmosphere is really not as important as the solar energy that reaches the lower atmosphere. If the physical

properties of the atmosphere and the earth did not vary, then about the only cause of climatic differences would be variations in input from the sun at the top of the atmosphere. The transmittance of the atmosphere does vary with time, however, and thereby influences the receipt of solar energy in the lower atmosphere and at the earth's surface. Historically, by far the greatest influence on atmospheric transmittance has been volcanic activity; significant changes of atmospheric transmittance have been measured following eruptions. A particular feature of volcanic activity is that it is sporadic and occurs in pulses, although the frequency and intensity of these pulses vary greatly (Bryson 1974).

Increased variability of weather has been linked with hemispheric cooling and associated amplification of the circumpolar wave pattern, which would cause greater extremes in weather, as indicated by the works of Bryson (1966, 1974) and Lamb (1966, 1969, 1977, 1978). Most studies of climatic variability have been concerned with variance on monthly, seasonal, or annual time scales, but it is also possible that the variability of daily temperatures is changing, which could affect the length of the growing season. An increase in the magnitude and/or frequency of very low daily minimum temperatures, for instance, could result in a later onset or an earlier end of the freeze-free season. The growing season is considered by some to be a simple but significant indicator of the impact of hemispheric temperature variations at the local level, yet the effect of different definitions for the growing season is poorly documented (Brinkman 1979).

The most basic manifestation of climatic change probably occurs in relatively small amplitude changes in the energy absorbed and in temperatures recorded in the oceans at low latitudes, but because these changes affect the energy and scale of the atmospheric and oceanic circulation they result in relatively bigger changes in high latitudes. This means that the changes are most easily determined in high latitudes. The amplification at high latitudes is also important in its own right because of the changes in the extent of ice and snow and, hence, albedo and the total heat intake (Lamb 1977).

Climatic changes, particularly those that involve lower temperatures, shorter growing seasons, or extremely variable weather patterns, have been correlated to tree growth rates in boreal regions. Quantitative assessment of the impact of climatic variations upon net primary productivity is not well advanced, however, primarily because the latter is dependent upon many factors or processes other than climate. Examples of the large number of factors and processes that influence boreal forest growth - some climatically linked and some acting independently of climate - are summarized in the following paragraphs.

2.4.2 Successional controls over primary productivity

Primary productivity changes that accompany various phases of ecological succession have been documented for a wide variety of ecosystems. In general, the productivity of an autotrophic plant cover at first increases slowly as its biomass accumulates, because the total surface area of leaves per unit area of land is still small. In a middle phase, productivity increases more rapidly and then decreases again when there is a decrease in photosynthesis. The latter occurs when the lower strata of leaves are significantly shaded. Productivity begins to decrease at high biomass, when the additional respiration of a large amount of biomass is not entirely compensated for by photosynthesis (Budyko 1974). These general principles apply to boreal forest ecosystems as much as they do to other communities of primary producers. Thus biomass accumulation at any given time may be as much a function of inherent successional processes within the ecosystem as a product of external factors such as climatic change.

2.4.3 Temperature and moisture controls over primary productivity

Under conditions of sufficient moisture, vegetation productivity is most affected by two factors - photosynthetically active radiation and temperature. The reduction of forest biomass with an increase in latitude, however, depends more on the reduction in duration of growing season than it does on lower air temperatures during the growing season (Budyko 1974). Actual evapotranspiration, which integrates the effects of available heat and soil water into one measure, is another variable that is a good predictor of primary production, litter decomposition rates, and various other plant processes. Evapotranspiration is of special value for prediction of productivity because it responds to all possible combinations of energy and moisture availability in an ecosystem (Meentmeyer et al. 1982, Rosenzweig 1968). A close link exists between photosynthesis and transpiration, which depends on net radiation. Hence there are good arguments for comparing production with net radiation, which is the standard Soviet practice (Hare and Ritchie 1972).

Lieth (1978) has presented other generalized predictors of primary productivity, particularly for the relationship between mean annual temperature and primary productivity. Productivities decrease along the gradient of decreasing temperatures from tropical to arctic regions. In the middle portion of this gradient, net primary productivity tends to double with each increase of 10°C in mean annual temperature (Figure 5). Decreasing length of the growing season in the colder climates may have as much to do with this as temperature itself (Whittaker 1975).

There is a general tendency for biomass, as well as productivity, to decrease along gradients of decreasing moisture and temperature.

Biomass values are mostly in the range of 20-60 kg/m^2 for mature forests, 4-20 kg/m^2 for woodlands, 0.5-3.0 kg/m^2 for grasslands, and 0-2 kg/m^2 for deserts and tundra. The relation of biomass to productivity is sometimes expressed as the biomass accumulation ratio, which is the ratio of dry weight biomass to annual net primary productivity. Such ratios for aboveground parts of plants vary from 1 to 3 in grassland, 10 to 30 in woodlands, and 20 to 50 in mature forests (Whittaker 1975).

Recent work by Russian researchers suggests that when heat is sufficiently great, extra moisture will yield greater primary production, but when heat is inadequate excess moisture can result in less production (Bazilevich et al. 1971). An example of the latter has been demonstrated in Quebec by Bellefleur and Auclair (1972). Since precipitation in boreal regions of Quebec is relatively high and temperatures are cool, moisture is excessive and forest growth is limited on sites that have less than adequate drainage. A number of boreal forest studies have indicated that soil moisture drainage is a major vegetational determinant (Bellefleur and Auclair 1972).

In the relatively humid climatic conditions of the boreal zone, soil moisture content is usually high enough to provide trees with the necessary amount of water during the best height growth period. Consequently drought does not have a large influence on the height growth of boreal trees. Studies carried out on the influence of various environmental factors on the length of the annual shoot have confirmed the general absence of a moisture-growth relationship in boreal climatic conditions. The strongest correlation between the length of annual shoot and various environmental variables was found with the temperature conditions of the summer preceding the shoot elongation (Hart and Leikola 1974).

In Finland no consistent correlation was found between precipitation and diameter growth of trees. Further south, in central Europe, growth of trees is evidently proportional to precipitation. It is thought that moisture may exert some influence in Finland, too, but its significance is hard to ascertain because rainfall and temperature of the growing season are usually more or less inversely proportional. It is noticeable that very dry summers in Finland are unfavorable to tree growth on the driest sites, just as very rainy summers are unsuitable for trees that grow on peatlands (Mikola 1956). While precipitation during certain months may be correlated with growth, the responses do not follow clear seasonal trends and are not as easy to interpret as the temperature responses. The Alaskan documentation of a positive correlation between growth and precipitation during summer months of the current growing season suggests that internal water stress can limit photosynthesis at subarctic tree line sites when temperatures are high. Relationships of this type are commonly found on arid or semiarid sites where moisture stress limits growth (Garfinkel and Brubaker 1980).

The presence of extensive wet areas in boreal regions where there is low precipitation is largely the result of underlying permafrost. Increases in thickness of the active layer (caused by better surface drainage on steeper slopes, more permeable materials, the nearness of a stream, or by warmer soil temperatures on south-facing slopes) create soils with improved internal drainage. On such sites, white spruce is established and grows at a much faster rate than white or black spruce on saturated soil with a thin active layer (Sakai et al. 1979).

One study in the central taiga region of the U.S.S.R. suggested a definite relationship between the formation of peat bogs and climatic fluctuation. The period of accumulation of the horizon of heavily decomposed peat appeared to correspond to a previous period of warming and increased aridity. The intermediate layer accumulated in a period of gradual moisture increase, and the overlying peat layers, with evidence of periodic flooding, originated in a later period when there were peaks of precipitation (Dolgushin 1969). An unusual aspect of this particular study site was that tree growth, especially at the beginning and in the middle of wet periods, was directly proportional to precipitation and had little relationship with temperature. At first glance such a relationship may seem paradoxical in an area of excess moisture and insufficient heat. One explanation is that most of the trees in the study area suffer either from oxygen deficiency in the soil or from a shortage of nutrients. In wet periods, especially if the amount and frequency of precipitation increases in June and July, the situation changes fundamentally. Precipitation carries both oxygen and nutrients into the soil. When the general moisture supply of an area is increasing, the more highly mineralized waters are extruded from the subsoil toward the surface. This phenomenon is undoubtedly promoted by the process of diffusion, in which the precipitated moisture becomes saturated with chemicals ascending from the ground water. At the same time, surface runoff increases, carrying a greater amount of nutrients and oxygen over the surface per unit of time, and this, as a general rule, tends to promote the functioning of root systems. As a result, there can be a temporarily beneficial effect for tree growth during periodic wet periods (Dolgushin 1969).

Despite the influences of moisture upon growth that are outlined above, there is broad agreement that tree growth close to altitudinal or latitudinal range limits of a species is mainly controlled by temperature. This control is exerted mainly during the current growing season, especially in the early part. Temperature during the warmest part of the day is apparently of particular importance. There also seems to be some effect from temperature variations during the preceding season (Bray 1971), as outlined in more detail below.

Data from studies near the northern Scandinavian tree line indicated that diameter growth of

trees depends closely on the temperature of the growing season. A clear correlation exists between diameter growth of pine and the July temperature. Toward the southern part of the boreal forest zone, the correlation weakens. There is evidence that diameter growth of pine depends mainly on temperature in the late part of the growing season (July) while that of spruce is more dependent on the temperature of early summer (June). Variations in the width of earlywood, the inner part of the tree ring formed in spring, are much smaller than variations in width of latewood. The earlier that growth commences in spring, the broader the latewood, both absolutely and relatively. Higher temperature in middle and late summer also promotes a broader band of latewood (Mikola 1956).

Annual height growth of Scots pine is determined mainly by temperature of the preceding summer. Good correlation exists between length of the terminal shoot and the July and August temperature of the preceding year. This is explained by the fact that the number of needles on a shoot is predetermined in the bud, which is formed in the preceding summer, and the length of shoot depends mainly on the number of needles it bears. Length of needles depends on climatic conditions prevailing during their growth, with temperature being the most important factor (Mikola 1962).

Similar to growth in length, radial growth also has two stages. The formation of earlywood is partly dependent on the quantity of nutrients stored in the tree over winter. It is for this reason that radial growth is influenced to some degree by temperature of the previous summer. The formation of latewood seems to correlate better with temperature during the current season than with temperature of the previous summer (Hustich 1978).

White spruce differs from black spruce in its response to climate, although in the southern portion of their range the growth rates of these two species of spruce are quite similar. As the climate becomes more severe, however, the average growth of black spruce decreases more rapidly than that of white spruce. This may be due to differences in sites occupied by the two species, since black spruce is found on many types of sites, while white spruce is generally restricted to sites with better soils. There may also be factors involved that are related to biological differences between the two species (Mitchell 1967). Species differences in growth responses to climate have also been recorded in Scandinavian studies, where the pronounced variation of pine growth rings was not evident in spruce data. It appears that over a wide geographical area the effect of climate on ring growth was recorded in a more uniform manner in the annual rings of pine than it was in spruce. The harsher the climatic conditions under which annual ring formation takes place, the more strongly accentuated will be the record of extremely good or poor years. Better correlations between climate and ring data were found from the more northerly Scandinavian

locations. As one progresses further north, annual ring formation of pine appears to be increasingly dependent upon weather conditions during the year prior to ring formation. Data from spruce obtained from progressively more northern locations also indicate that more northerly locations are more strongly influenced by weather conditions of the year preceding ring formation than is the case further south. The tendency was not as pronounced or as statistically reliable for the spruce data as it was for pine (Eklund 1956).

2.4.4 Temperature influences upon distribution of the boreal zone

Temperature also exerts an influence over boreal biomass accumulation through its relationship to the geographic distribution of boreal vegetation. The northern tree line appears to react to relatively short-term fluctuations in climate; however, a distinction has been made between advancing and retreating tree lines. A tree line is probably capable of advancing relatively rapidly after an increase in temperature, whereas it is slower to retreat in response to deterioration in the climate, since the trees can live for many hundreds of years without reproducing or else can reproduce vegetatively to a limited extent, provided the climatic change is not so great as to cause fully grown trees to die (Tukhanen 1980).

There is also evidence, from studies of forest outliers within the tundra, that temperature changes need not be great to have a significant influence. Forest outliers are thought to be relicts from a former forest cover. They have survived by virtue of their special topographic and edaphic situations. The outliers are insensitive to the kind of climatic stress that might damage trees on upland sites. The threshold for disappearance of widespread forest cover, therefore, is of less magnitude than that for removal of all trees. A regional temperature decrease of only 3-5°C is thought to be enough to initiate reduction of the forest cover in northern Canada. A decrease of only 1°C, over a prolonged period, may be sufficient to effect movement of the forest edge through a distance of 150 km or more (Kay 1976). Bryson and Wendland (1967) stressed that there is inadequate recognition of the fact that the impacts of minor climatic variations are greatest at the boundaries of biotic zones; ecotones are sensitive to climatic change and the central parts of biotic zones are far less so.

There are two other interesting aspects of temperature controls over distribution of the boreal zone. First, all zones bend southward when near cold seas such as Hudson Bay, or the Atlantic Ocean off Labrador and Newfoundland. The woodland-tundra in these sectors, and even the subarctic zone near James Bay, is very narrow due to this southward depression. The Baltic Sea, although cool in spring, has an opposite effect, presumably because of comparatively long-lasting autumnal warmth. Secondly, when not influenced by the cold sea effect,

the width of the zones and subzones is dependent on the general slope of the land. If the slope is toward the south, zones tend to be narrow, and if it is toward the north they are wider. This is an altitudinally induced temperature effect that is evident in nonmountainous areas, although there is a tendency to associate such altitudinal influence with only mountainous areas (Sjörs 1963).

One much-debated problem in phytogeography concerns the extent to which vegetation is affected by rare extremes of climate, such as exceptionally late frost in spring, early frost in autumn, long periods of drought, or severe frosts that occur before there is a snow cover. Average climates described in terms of mean values are highly abstract in character, and for this reason it is logical to emphasize the importance of extreme values. The impact of extreme conditions depends on the extent to which the exceptional circumstances deviate from the normal, the length of time they last, and how often they recur. It has been suggested that extreme circumstances may bring about temporary alterations in the distribution of individual species, and perhaps even determine the boundaries of their occurrence, but the regional vegetation is generally considered to be governed by the average climatic conditions (Tukhanen 1980).

2.4.5 Organic matter accumulation in boreal forest ecosystems

The gradual buildup of organic matter, in the absence of fire, is one of the dominant features of boreal forest ecosystems. As primary or secondary succession progresses, organic matter accumulates both in the standing crop of trees and shrubs and in forest-floor organic debris. The forest floor acts as an effective insulating blanket, cooling the mineral soil as forest floor biomass accumulates. Reduced soil and forest floor temperatures slow the decomposition rate, promoting organic matter accumulation. With advancing succession, a higher forest floor moisture content is reflected in the establishment and increased productivity of bryophytes. At any time fire or flooding may disrupt this progressive accumulation of organic matter and return the system to an earlier stage in succession (Van Cleve and Viereck 1981).

A primary reason for increased accumulation of forest floor biomass is the predominance of moss in later stages of succession, particularly in spruce stands. The moss layers produce significant biomass, which in conjunction with vascular plant litter deposition results in the thickening of the forest floor (Zasada et al. 1977). Such an accumulation of nutrients in moss and organic layers of the forest floor runs counter to expected trends in temperate forest successions. There is some evidence that in boreal forests maximum nutrient cycling may come midway in post-fire vegetation sequences, and the accumulation of biomass may continue indefinitely in the absence of fire (Heinselman 1981). On the other hand, Zasada et al. (1977) suggested that forest floor biomass eventually does reach equilibrium where decomposition

equals annual input, generally at least 50 years in birch and aspen ecosystems and longer in black spruce ecosystems in interior Alaska.

2.4.6 Fire as an influence on primary productivity

Fire has been the most important overall disturbance in boreal ecosystems; in conjunction with aspect, it accounts to a significant degree for the patterns of forest distribution. Fires destroy the overstory and forest floor, resulting in the release of significant quantities of nutrients. Surface and subsurface temperatures increase after fire because overstory shading is reduced and organic layer thickness is decreased. Where permafrost is present, the thickness of the active layer increases. The relative degree to which ecosystem development is set back depends on fire intensity. By returning nutrients to an available form, thereby increasing site productivity, fire has the effect of counter-balancing the nutrient tie-up that results from the inherently slow decomposition rate of boreal forest floor organic matter (Viereck and Schandelmeier 1980).

2.4.7 Local topography as an influence on primary productivity

As in any terrestrial landscape, primary productivity in boreal forest ecosystems varies over short distances in response to differences in topography, water availability, soil quality, and successional stage (Lieth 1975). It is known that vegetation behaves differently on slopes with different aspects. For example, differences in the stage of plant development have been reported to range from 5 to 18 days when north-facing and south-facing slopes were compared (Dolgin 1970). The low growth rate of white spruce on north-facing slopes and in bogs and muskegs results, in part, from the effect of topography that favors development of an insulating organic mat. The result is a cool soil temperature, making the bioclimate similar to that of forest patches in the tundra. The thickness of the active layer is a reliable indicator of conditions that influence the distribution and growth of trees. The greater productivity of spruces on south-facing slopes where there are deep active layers may be explained by a combination of factors such as good drainage, high soil temperature, availability of nutrients, and well developed soil (Sakai et al. 1979). In general, the poorest correlations between plant growth and macroclimate occur in communities of lower slopes, meadows, shorelines, and marshes, because the presence of abundant water tends to override other environmental influences (Larsen 1971).

2.4.8 The complexity of growth-regulating factors in the boreal zone

The influences of climatic variables upon plant growth are complex, and it is not surprising that the literature contains a confusing array of apparent relationships between climate and plant growth. As indicated in Section 2.4.3, one unifying theme is

that the overall development of many plants follows a remarkably close relationship with temperature. The relationship between soil temperatures and plant growth may well be more direct than that between mean air temperatures and growth (Boughner 1964). In any case, the temperature fluctuations that have been inferred from tree-growth variations are in broad agreement with existing knowledge from other sources such as instrumental records, stable isotope ratios in ice and wood, tree-line fluctuations, glacier fluctuations, the extent of Arctic pack ice, glaciofluvial sedimentation rates, the incidence of rockfalls, avalanches, other natural disasters, vine harvest dates, and crop failures (Mathews 1976). Some researchers have stressed that the sensitivity of vegetation to climatic change is expressed in time scales ranging from centuries to millenia. This sensitivity is in marked contrast to the usual failure to establish relationships between vegetation and climate based on yearly or decadal means, which has led some scientists to consider climatic change of little significance in relation to vegetation dynamics (Bray 1971).

It is evident that temperature-growth relationships are not as straightforward as once thought. For example, in addition to the expected positive correlation with current summer temperature, growth exhibits a strong positive correlation with previous autumn temperature and negative correlations with previous summer, winter, and spring temperatures. The positive response of growth to current summer temperature suggests that warm temperatures can increase rates of net photosynthesis and enhance growth in tree-line environments during the growing season. The prominent positive correlation with previous autumn temperature suggests that warm autumn temperatures lead to increased photosynthesis after the end of the growing season, resulting in greater reserves of carbohydrates for the next year (Garfinkel and Brubaker 1980).

Adding to this complexity are other ecosystem processes that have profound influences upon net primary productivity, independently of climatic variation. Exemplifying this complexity is the fact that organic matter decomposition on the boreal forest floor may not keep pace with the accumulation of moss and humus, particularly on cold or wet sites. This potential for net accumulation of biomass has long been recognized in northern peatlands, but its significance in boreal ecosystems dominated by mineral soils and its relation to fire are just now being studied (Heinselman 1981).

In summary, it is useful to reiterate the complex processes that influence net primary productivity of boreal ecosystems, using as an example the Alaskan documentation of black spruce stands (Van Cleve et al. 1981, Viereck and Schandelmeier 1980, Zasada et al. 1977). It is hypothesized that in the long absence of fire the forest floor continues to thicken, progressively tying up nutrients. Moss and lichen productivity continues to increase compared with that of the tree

overstory, and the overstory becomes more open and less productive. Soil temperature continues to decrease and soil moisture increases, creating conditions that encourage the development of sphagnum mosses over feather mosses. This condition can eventually result in paludification of the site and the development of treeless bogs. Fire is thus a very important boreal ecosystem process that tends to disrupt the progressive changes outlined above and to allow the repeated reestablishment of successional sequences. In the black spruce ecosystem, fire serves to recycle the vegetation before it reaches the steady-state climax condition. The black spruce ecosystem supports the concept that most forest ecosystems change in patches of various sizes. This change is controlled both by intrinsic factors of the ecosystem and by extrinsic factors of the environment. Superimposed upon these processes are the diverse long-term climatic changes that are outlined in various references of this bibliography.

3. KNOWLEDGE GAPS

Some of the main unanswered questions that have been identified by authors of references in this bibliography are summarized below under two headings - climatic variation (Section 3.1) and production processes (Section 3.2). An overview of gaps in our knowledge of relationships between climatic factors and boreal forest biomass is presented in Section 3.3.

3.1 Unanswered Questions About Climatic Variation

Knowledge gaps relating to climatic variation center around sun-weather relationships, atmospheric circulation patterns, and the influences of volcanic eruptions upon atmospheric transmittance and surface temperatures.

If the sun changes in ways that affect world climate, high scientific priority needs to be given to monitoring of solar behavior. Researchers have stressed the importance of determining whether and how the radiative flux from the sun changes and in what time scales. To determine whether the solar constant is varying requires long-term monitoring of both the total solar radiation and its terrestrially important spectral components. This assignment is not an easy one, for it demands a capability to sense changes of no more than 0.1% in a decade, carried out over many decades (Eddy 1977). Some investigators have simulated the course of global mean surface air temperature over the past 370 years by use of a formula that expresses variations of the available solar energy in terms of sunspot numbers. It has been suggested that high priority should be given to obtaining high precision, extra-terrestrial measurements of variations of solar beam intensity (Lamb 1977).

The most promising avenue for investigation of climatic change is likely to be through study of changes in the general circulation of the atmosphere and oceans. Circulation

studies provide a unified, synoptic view of the miscellaneous climatic variations noticed in different parts of the world (Lamb 1969). Changes in circulation patterns are not well documented, however. For example, the suggested trend of the North Atlantic circulation toward lower latitudes in winter requires further study. A continuing watch upon the main arms of the general atmospheric circulation has been suggested as the best approach for an early warning of the onset and progress of climatic changes (Lamb 1966, 1969).

Sudden blocking of wind circulation patterns can produce an extreme season of drought or raininess or unusually high or low temperatures. It is the suddenness of such changes that has the greatest impact on the biosphere. There is evidence that the late 1970s represented one of those periods of frequent blocking of the westerlies, when the year-to-year variations increase, and which could signal lasting changes. There is therefore a need for research that would yield a better understanding of circulation patterns and greater ability to forecast circulation changes (Lamb 1978).

A key climatic question is whether variations in circulation intensity represent an overall change in the circumpolar vortex or whether they indicate only a shift in tropospheric wave pattern. The problem of linking changes in climatic conditions with circulation changes has received only limited attention. The principal area of uncertainty concerns the basic characteristics of atmospheric circulation fluctuations and especially the manner in which these fluctuations are regionally expressed. The complex relationships between wave amplitude and spacing, circulation intensity, and the nature of latitudinal displacements of global wind systems are inadequately known (Barry 1978). One example from the work of Bryson demonstrates how these questions relate to the boreal forest region. The median July position of the arctic front in summer is in close agreement with the northern margin of the boreal forest zone in central Canada (Bryson 1966). Work by Barry (1967), however, indicated that the relationship between the arctic front and the forest/tundra boundary may require further study in eastern Canada where there is a broad baroclinic zone and where altitude has an influence on location of the forest/tundra boundary.

Contemporary climatic change has been found to depend to a large extent on variations of atmospheric transmittance, which change the amount of solar radiation that reaches the earth's surface and are associated with varying levels of volcanic activity (Budyko 1969). The more successful simulations of the course of hemispheric or zonal temperatures over the past century have been based on the assumption that the transparency of the cloudless atmosphere has varied in response to variations of volcanically produced turbidity. In part, these models help distinguish between variations of direct-beam solar radiation observed at the

surface and variations produced by volcanic debris that changes the atmospheric transparency. Because of these relationships, researchers have stressed that it will be necessary to estimate future levels of volcanic activity if the objective is to estimate future climatic conditions (Bryson and Goodman 1980).

Many questions remain unanswered with regard to the climatic influences of volcanic eruptions: Are there different effects if eruptions occur at different latitudes and at different times of the year? What are the spatial patterns of climatic change following individual eruptions? Are there long term fluctuations in the frequency of explosive volcanic activity? How can the effects of an individual eruption be distinguished in the 'noisy' climatic record (Sear and Kelly 1980)? The year-to-year variability of climate is such that the effects of any one eruption, unless it is of a very great magnitude, are unlikely to be readily apparent. One of the major problems in determining the climatic impact of past eruptions has been a lack of firm data. There is insufficient information concerning the amount and composition of the material injected into the stratosphere by previous major eruptions. It is also only in recent years that reliable observations of the atmosphere, and particularly the upper layers, have become readily available. The catastrophic eruption of Mount St. Helens afforded an important opportunity to study in detail the physics, chemistry, meteorology, and climatology of the impact of a major middle-latitude volcano (Sear and Kelly 1980).

Climatic records during the 20th century have demonstrated the unreliability of the concept of a climatic 'normal' state and the need to consider climate as an environmental variable (Barry 1978). Much of the research done to date on the basis of assumed normal periods, for example from 1931 to 1960, should be reassessed; it has been suggested that a realistic perspective of recent climatic fluctuations must span at least the last 500 years if one wishes to characterize the rates, magnitude and possible causes of climatic changes (Barry 1978).

With regard to atmospheric levels of CO_2, Hare (1981) stressed that, aside from the need to maintain a CO_2 monitoring program, it will be necessary to maintain a watch on the climate itself. The natural variability of climate - the noise - is so great that slow changes of temperature and precipitation - the signal - will be very hard to detect. Because Canada covers the range of latitudes likely to be most affected, it is important that there be attempts to detect the influences of CO_2 increase upon temperature and precipitation records and, if possib'e, to devise ways of separating this signal from other causes of temperature and precipitation changes.

In addition to the standard types of meteorological parameters, such as monthly precipitation and temperature, new parameters should be examined for the purpose of dendroclimatological analyses. Such new parameters should include degree-days above a threshold temperature as

a variable affecting tree growth. It has been suggested that a parameter similar to the Palmer Drought Severity Index, which combines the effect of temperature and moisture, could be developed for northern tree-line studies (Jacoby 1980). Our knowledge of climatic variation may also be improved if some of the less frequently used forms of proxy data, such as varved clays (Renberg and Segerström 1981) or speleothems (Harmon 1980), were further tested for correlation with dendrochronological indicators of climatic change.

3.2 Unanswered Questions About Boreal Production Processes that Function Independently of Climate

We do not yet understand all of the ecological ramifications of the fact that in some boreal ecosystems there is up to ten times more organic matter in the mineral soil, below the forest floor, than there is in the tree layer (Van Cleve et al. 1981). The study of dead organic matter in the forest floor and in the underlying soil has been neglected in research on biological productivity of natural ecosystems, except for several recent studies in Alaska such as those by Van Cleve et al. (1981). Man's impact on soil carbon is increasing, largely as a result of agricultural practices but also because of increased whole-tree logging that removes from the growing site the tree-root systems and attached soil; because of these trends, increased attention should be given to quantification of the role of dead organic matter in boreal production processes (Ajtay et al. 1979).

The amount of surface organic debris accumulated in late successional stages of black spruce stands may be between four and five times that found in live, aboveground tree biomass. The forest floor generally plays a more significant role in biomass and nutrient storage and in controlling soil temperature in these black spruce ecosystems than in floodplain or white spruce upland successional sequences. Fire has a profound influence on these natural successional trends. Substantial, but currently unknown, reduction undoubtedly occurs in tree root-system biomass following fire (Van Cleve and Viereck 1981). Although there has been only limited research on fine-root biomass in boreal forest ecosystems, there are indications that fine-root production and belowground turnover exceed levels conventionally expected in forest ecosystems. Future ecosystem studies need to provide better estimates of the rates of change in biomass of root systems, rather than solely structural descriptions of them (Persson 1979).

The classical interpretation of succession is that successive vegetation stages modify the environment, preparing the way for subsequent stages. An increase of net production to an asymptote at climax is a widely accepted view of succession on well-drained sites. For secondary forest succession, however, only a few cases of asymptotic increase have been reported, and these cases are

supported by only limited data. An alternative hypothesis is that a finite quantity of resources is available for plant growth each year, with the result that, after an initial but brief recovery period, production is independent of stand age. In general, the question of whether successional communities are more productive than climax ones is still unanswered for most successional series in the world (Peet 1981).

The potential role of nutrient availability in biomass accumulation cannot be ignored. It is logical to hypothesize that nutrient losses have a negative influence on primary production. Early in succession, production should theoretically be relatively high due to a large pool of available nutrients. After this pool has been exhausted, production should be limited by nutrient inputs. When biomass (both living and dead) has reached a stable level and nutrients are not being used in formation of new biomass, production should be less limited by nutrients. Changes in available nutrient pools thus have the potential to partially counteract the tendency for a high peak in the middle stages of stand development. The present literature suggests that more information is needed before the importance of nutrient limitation as a negative feedback mechanism can be adequately evaluated in boreal ecosystems (Peet 1981).

The productivity implications of ecological changes from boreal woodland to peatlands, or vice versa, are not documented in detail. Where drainage of boreal wetlands is involved as a forest management practice, there is considerable uncertainty about the effects of drainage upon the physiology and growth of boreal species (Payandeh 1973). Furthermore, the effects of short-term climatic variation upon peatland dynamics and the net influence of either decreasing or increasing peatland areas upon total biomass accumulation in the boreal zone is not yet quantified (Dionne 1979).

3.3 Research Questions on Relationships Between Climatic Factors and Boreal Forest Biomass

Preceding sections of this literature review have highlighted a number of knowledge gaps about climatic variables and production processes in boreal ecosystems. Such knowledge gaps will be addressed by future climatological research and future studies of primary production. Of more immediate interest is the specific research that is needed to focus on the direct links between climatic factors and boreal biomass accumulation.

A fundamental research requirement is the identification of reference or benchmark sites in which certain boreal forest ecosystems would be set aside to provide specific documentation of growth responses to climatic changes. This implies long-term documentation, but it may not need to be as long as commonly thought. Many references in this bibliography indicated that significant temperature changes have

occurred in the northern hemisphere in as short a time as one decade. A considerable number of the references provide evidence that nonclimatic factors such as soil nutrient availability, topography (aspect), or successional stage can control production processes to a degree that masks the influence of climatic variability. Thus there is a limited opportunity to come to scientifically defensible conclusions about direct links between climatic variation and production processes, unless the other highly influential variables are held constant. This requirement limits the conclusions that can be drawn from climate/growth studies done at different locations. The identification of benchmark sites that could be protected to ensure successive remeasurement of climate/growth relationships appears to be one of the best ways to research some of the knowledge gaps identified in this review.

It is beyond the scope of this study to identify where such benchmark sites should be located; however, the most productive return on any research investment could be expected if the selected sites included boreal forest stands composed of those tree species for which there is now the best data on production processes and biomass accumulation. As the summary in Table 3 indicates, the boreal tree species for which there is now the most comprehensive aboveground and belowground biomass information available are Scots pine in Europe and black spruce, white spruce, and trembling aspen in North America. Benchmark sites selected to include one or more of these four species, plus additional study sites that contain the oldest known individual trees for dendrochronological analyses, commonly white spruce in Canada and Alaska, should be given highest priority for long-term protection as outdoor laboratories.

Some of the research objectives that appear to have high priority for documentation of climate/biomass relationships at designated benchmark sites are outlined in the paragraphs below.

Several researchers have stressed that the problem of linking changes in climatic conditions with atmospheric circulation changes has received only limited attention (Barry 1978, Lamb 1978). Because the principal area of uncertainty is the way in which atmospheric circulation fluctuations are manifested regionally or locally, one research objective should be to relate growth patterns in one or more boreal tree species at one or more benchmark sites to fluctuations between zonal circulation types and meridional circulation types.

The subject of atmospheric circulation changes is singled out as one of prime importance because it appears to fundamentally influence the investigation of several aspects of climate/biomass relationships. This literature review revealed the importance of further research on the influence of extreme climatic events upon tree growth (Tukhanen 1980). There is clearly a need for such documentation on a species by species basis for trees of the boreal zone.

TABLE 3. REFERENCES (AUTHOR/DATE) FROM THIS BIBLIOGRAPHY THAT PROVIDE DATA ON BIOMASS OF BOREAL TREE SPECIES

TREE SPECIES	ABOVEGROUND TREE BIOMASS DATA	ABOVEGROUND AND BELOWGROUND TREE BIOMASS DATA
1. Alder (**Alnus** spp)	Galvans 1976 Major 1974 Øvstedal 1980	Zasada et al. 1977
2. Aspen, trembling (**Populus tremuloides** in North America; **Populus tremula** in Europe)	Alban et al. 1978 Alemdag & Horton 1981 Bella & De Franceschi 1981 Bella & Jarvis 1967 Bray & Dudkiewicz 1963 Carlisle 1976 Cragg et al 1977 Galvans 1976 James & Smith 1977 Johnstone & Peterson 1980 Ker 1980 Lavigne & van Nostrand 1981 MacLean and Wein 1978 Pastor and Bockheim 1981 Perala 1973 Peterson et al. 1970 Pollard 1971, 1972 Van Cleve & Noonan 1975 Zavitkovski 1971 Zoltai 1978	Alban et al. 1978 Stanek & State 1978 Zasada et al. 1977
3. Birch, white (**Betula papyrifera**)	Hakkila 1979 Kerr 1973, 1974, 1980 Lavigne & van Nostrand 1981 Van Cleve & Noonan 1975 Van Cleve et al. 1979	Baskerville 1966 Stanek & State 1978 Zasada et al. 1977
4. Fir, balsam (**Abies balsamea**)	Art & Marks 1971 Baskerville 1965, 1966 Ker 1973, 1980 Ker & Van Raalte 1981 Lavigne & van Nostrand 1981 Young et al. 1979	Baskerville 1966 Stanek & State 1978
5. Larch a) tamarack (**Larix laricina**)	Ker 1980 Lavigne & van Nostrand 1981 Zoltai 1978	
b) various European species of larch	Moskalyuk 1980 Rodin 1979	Walter 1968
6. Pine, jack **Pinus banksiana**	Alban et al. 1978 Doucet et al. 1976 Hegyi 1972 Ker 1980 MacLean & Wein 1976, 1978	Alban et al. 1978 Morrison 1974 Stanek & State 1978

Continued ...

TABLE 3 (Continued)

TREE SPECIES	ABOVEGROUND TREE BIOMASS DATA	ABOVEGROUND AND BELOWGROUND TREE BIOMASS DATA
7. Pine, Scots (**Pinus sylvestris**)	Hakkila 1979 Kubin 1977 Major 1974	Albrektson 1980 Astrologova 1976 Bringmark 1977 Flower-Ellis and Persson 1980 Persson 1979 Rodin 1979 Walter 1968
8. Poplar, balsam (**Populus balsamifera**)	Bella & De Franceschi 1990 Johnstone & Peterson 1980 Van Cleve & Viereck 1981 Van Cleve et al. 1979	Zasada et al. 1977
9. Spruce, black (**Picea mariana**)	Barney & Van Cleve 1973 Barney et al. 1978 Johnson & Vogel 1966 Ker 1973, 1974, 1980 Lavigne & van Nostrand 1981 Moore & Verspoor 1973 Sims and Stewart 1981 Van Cleve et al. 1981 Van Cleve & Viereck 1981 Van Cleve et al. 1979 Viereck & Schandelmeier 1980 Weetman & Harland 1964	Rencz 1976 Stanek & State 1978 Van Cleve et al. 1981 Zasada et al. 1977
10. Spruce, Norway (**Picea abies**)	Hakkila 1979 Kellomaki et al. 1977 Kubin 1977	Kubin 1977
11. Spruce, white (**Picea glauca**)	Alban et al. 1978 Barney & Van Cleve 1973 Baskerville 1966 Fraser et al. 1964 Ker 1980 Ker & Van Raalte 1981 Van Cleve & Viereck 1981 Van Cleve et al. 1979 Viereck & Schandelmeier 1980	Alban et al. 1978 Baskerville 1966 Lavigne & van Nostrand 1978 Stanek & State 1978 Zasada et al. 1977
12. Willow (**Salix spp**)	Alexandrova 1970 Siren 1966	Zasada et al. 1977

Similarly, Brinkman (1979) stressed that alternative statistical definitions of the growing season may influence our conclusions about relationships between climate and plant growth. Further studies on extreme climatic events and growing season definitions are both examples of research that would have direct links to the broader subject of atmospheric circulation changes.

Most boreal dendroclimatic studies emphasize the influence of temperature upon tree growth, but Jacoby (1980) and others have suggested that moisture stress near the end of the growing season may be of importance in some parts of the boreal forest. Although the search for moisture/growth relationships in boreal tree species does not appear to be a high priority research subject, there should be a continued search for relationships between growth of boreal tree species and various meteorological variables not now used, particularly those that might combine the effects of temperature and moisture as an index of net primary productivity.

Many investigators have stressed that an outstanding feature of boreal forests is the accumulation of nutrients and carbon in the forest floor and in the soil beneath the humus layer. Rates of nutrient cycling in boreal forest ecosystems are regulated by events that control the accumulation and decomposition of organic matter on the forest floor. Fire is dominant among these controls. Because of the fundamental ecological role played by fire in boreal forest ecosystems, the links between climatic factors and biomass accumulation in boreal forests must inevitably involve research to further quantify climatic influences upon size, frequency, and intensity of boreal forest fires.

4. CRITERIA FOR SELECTION OF BIBLIOGRAPHIC SUBJECTS

4.1 Overview of Subjects Included and Excluded

Three broad types of articles were reviewed for this study: publications that provided only biomass or net primary productivity information; those that gave only descriptive climatic information; and those that dealt with relationships between forest biomass accumulation and climatic variables. A more detailed subdivision of the subject matter covered is provided in Table 4. The 25 subheadings listed in Table 4 were used for the subject index of this report. Some of the main assumptions and reasons behind the seven main headings, which indirectly served as criteria for selection of subjects to include in this review, are outlined in sections 4.2 to 4.8 below.

Prediction of the impact of climatic variation on biomass accumulation requires an understanding of not only climate/growth relationships but also other factors or processes that influence rates of net primary production and buildup of biomass. In many cases, forest growth rates appear to be so strongly influenced by local

TABLE 4

SUBJECT INDEX FOR LITERATURE REVIEW OF IMPACT OF CLIMATIC VARIATION ON BIOMASS ACCUMULATION IN THE BOREAL FOREST ZONE

1. BIOMASS OF BOREAL VEGETATION (data on biomass and net primary productivity)
   - 1.1 BIOMASS (TREE)
   - 1.2 BIOMASS (SHRUB/HERB)
   - 1.3 BIOMASS (MOSS/LICHEN)
   - 1.4 FOREST GROWTH AND YIELD (growth data not expressed as biomass)

2. CLIMATE OF BOREAL ZONE (at macroclimatic and mesoclimatic levels of detail)
   - 2.1 CLIMATE (AIR MASSES) (including storm tracks, fronts, winds and cloudiness)
   - 2.2 CLIMATE (PRECIPITATION) (including evapotranspiration)
   - 2.3 CLIMATE (TEMPERATURE)
   - 2.4 CLIMATE (INSOLATION)
   - 2.5 CLIMATE (CARBON DIOXIDE LEVELS)

3. CLIMATE/GROWTH RELATIONSHIPS IN BOREAL ZONE
   - 3.1 CLIMATE/GROWTH (DIRECT RELATIONSHIPS)
   - 3.2 CLIMATE/GROWTH (INDIRECT INFLUENCES) (fire, insects, or pathogens)
   - 3.3 CLIMATE/GROWTH (MICROCLIMATE)
   - 3.4 CLIMATE/GROWTH (LATITUDE) (latitudinal or altitudinal growth gradients)

4. CLIMATIC CHANGE IN BOREAL ZONE (long-term changes, predating meteorological records, and including all forms of proxy data)
   - 4.1 CLIMATIC CHANGE (HYPOTHESES)
   - 4.2 CLIMATIC CHANGE (DENDROCHRONOLOGY)
   - 4.3 CLIMATIC CHANGE (PROXY DATA) (proxy data other than tree rings)

5. CLIMATIC VARIATION WITHIN BOREAL ZONE (annual or short-term changes, based on meteorological records)
   - 5.1 CLIMATIC VARIATION (REGIONAL)
   - 5.2 CLIMATIC VARIATION (TEMPORAL)
   - 5.3 CLIMATIC VARIATION (TEMPERATURE)
   - 5.4 CLIMATIC VARIATION (PRECIPITATION)

6. GROWING SEASON OF BOREAL ZONE
   - 6.1 GROWING SEASON (LENGTH)
   - 6.2 GROWING SEASON (DEGREE-DAY TOTALS)
   - 6.3 GROWING SEASON (FROSTS)

7. TREE-LINE STUDIES OF BOREAL ZONE (including shifts in boundaries of boreal zone)
   - 7.1 TREE-LINE STUDIES (GROWTH)
   - 7.2 TREE-LINE STUDIES (CLIMATE)

variations of nonclimatic factors, such as topography, soil moisture, or stage of ecological succession, that productivity changes triggered by climatic shifts are difficult to detect. For these reasons, the literature review was sufficiently broad to include references that document the fact that many nonclimatic factors have an important influence on forest productivity. This step required a broader subject coverage than was specified in the original objectives. Rigorous selection was required to keep the literature on nonclimatic controls of boreal forest growth to manageable levels, with the result that there is rather incomplete coverage of certain subjects. The growth-related subjects that were reviewed in only enough detail to demonstrate their role in boreal production processes are listed below:

a) the large amount of information on nutrient cycling was generally omitted except for a few references, such as Morrison (1973), Rodin and Bazilevich (1967), Van Cleve and Noonan (1975), or Zasada et al. (1977), from which data on biomass and turnover rates could be extracted; the related literature on humus of boreal forest ecosystems, exemplified by the work of Weetman (1974) in Canada, was reviewed only to the extent necessary to make the point that to understand boreal ecosystems one must understand forest floor processes;

b) publications on physiological processes fundamental to organic matter formation, particularly photosynthesis and respiration, were generally not reviewed because of the large, complex literature on this subject; Linder's recent compilation[1] of the 1891-1977 literature on photosynthesis and respiration in conifers confirmed that there is a substantial body of knowledge about the physiology of net primary production; the physiology of frost hardiness was also omitted from this review;

c) the reviewed article by Mattson and Addy (1975) demonstrates that phytophagous insects exert significant controls over biomass accumulation and net primary production rates, but the relations between weather variables, levels of insect or disease populations, and resulting growth of vegetation was a subject too complex to cover in this review; fire as an indirect influence of boreal forest growth was given more comprehensive coverage than the literature on insects and diseases of trees, partly because fire is such a dominant factor in boreal ecosystem development and partly because of this study's interest in relations between burning of boreal forest biomass and atmospheric CO_2 levels;

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1. Linder, Sune. 1979. Photosynthesis and respiration in conifers. A classified reference list 1891 - 1977. Studia Forestalia Suecica 149. 65 p.

d) the literature on genetic diversity of boreal trees, as a factor influencing growth rates, was not covered in this review; data to substantiate the role of microclimate or other physical variables of sites that differ in their potential for tree growth was touched upon only briefly by inclusion of references such as Van Cleve et al. (1981) or Zasada et al. (1977);

e) the research of Bolin (1980), Dolgushin (1969), and Heinselman (1981) testifies to the subtle relationships that exist between peatland dynamics and climatic variation, but the effect of either decreasing or increasing peatland areas upon total regional biomass accumulation in the boreal zone is an important subject not addressed in this review; the subject of how net primary production changes with forest succession in the boreal zone is introduced in this review by reference to articles such as Heinselman (1981) or Major (1974), but the coverage of this topic is far from complete;

f) influences of climate upon species composition of boreal plant communities and upon seedling regeneration and plant succession are subjects for which there is a relatively large amount of literature; in general, these subjects were omitted from the review unless there were accompanying data on biomass or growth rates; some exceptions were made for regeneration questions near the northern and southern limits of the boreal zone; for example, a number of tree-line studies deal with climatic influences upon tree regeneration without providing any information on standing crop or growth rates; some of these references were annotated since they provided information of fundamental importance about the present and potential latitudinal boundaries of the boreal forest region;

g) the forestry literature dealing with climatic influences upon wood characteristics other than weight, such as the research on basic wood density by Kellomäki (1975), was not exhaustively reviewed; similarly, the many growth and yield studies, with results expressed on a wood volume basis rather than a weight basis, were covered only at the level of review articles such as those by Bickerstaff and Hostikka (1977), Bickerstaff et al. (1981), or Rennie (1978); data on forest fuel weights, generated during a variety of fire research studies in the boreal forest regions, are other indirect sources of forest biomass information that were considered too numerous to review here;

h) the relatively large number of paleobotanical publications that deal with climatic changes over several millenia were selectively reduced by focussing mainly upon reports that provided information on the recent past; emphasis was placed upon climatic changes during the period in which the

oldest trees alive today may have been present - approximately 1 000 years or less;

i) without attempting comprehensive coverage of the literature, some of the less frequently used forms of proxy data, such as varved clays (Renberg and Segerström 1981) or speleothems (Harmon 1980) were introduced only to indicate that cross-correlations between dendrochronology and other proxy data may be a promising avenue of future research;

j) the large amount of literature on atmospheric carbon dioxide was selected to focus mainly on those publications that referred to the influence of boreal biomass burning upon CO_2 levels (Wong 1978); hypotheses on mechanisms of climatic change were not examined comprehensively but were introduced by inclusion of several review articles (Bolin 1980, Budyko 1974, and Lamb 1969, 1977) that included discussions of atmospheric CO_2 levels.

4.2 Biomass of Boreal Vegetation

Biomass of boreal vegetation, as an indexing category, included references that provided information on forest growth, with emphasis on data that were expressed on a weight basis. A separate indexing category, **forest growth and yield**, was used for references that provided data on a volume, site index, or basal area basis rather than a weight basis. Although most emphasis was on tree biomass, where data were available for shrub, herb, moss, or lichen components of boreal vegetation this information was also summarized and indexed. Root biomass data were not indexed separately and were included under **Biomass (tree)**. Many of the references that fell into the biomass indexing category did not contain information on climate.

The main variables included in the biomass indexing category were:

biomass - the amount of organic matter (fresh weight or dry weight) present on a unit area of land at any given time, commonly expressed as tonnes per hectare (t/ha) (this term is considered to be synonymous with standing crop or with phytomass);

net primary productivity - the rate of storage of organic matter in plant tissues in excess of respiratory use by plants during the measurement period, commonly expressed as tonnes per hectare per year (t/ha/yr) (this term was taken to be synonymous with apparent photosynthesis and net assimilation);

standing crop density - the weight of organic matter present per unit volume of forest stand space, commonly expressed as kilograms per cubic metre (kg/m^3).

Biomass stored at consumer levels, referred to as secondary productivity, was not reviewed in this study.

4.3 Climate of the Boreal Zone

Climatic subjects selected for review dealt with data at macroclimatic and mesoclimatic levels of detail and described variables thought to have the most direct influence upon primary production processes. These included air masses, precipitation, temperature, insolation, and atmospheric concentrations of carbon dioxide. Information on storm tracks, locations of fronts, winds, and cloudiness were included in the indexing term **air masses**; evapotranspiration information was indexed under **precipitation.** Many of the articles selected for inclusion under the climate indexing category did not contain any information on biomass. The literature on atmospheric carbon dioxide was selected to focus mainly on references that identified relationships between forest biomass burning and atmospheric carbon dioxide levels; little of this literature was specific to the boreal forest region.

4.4 Climate/Growth Relationships in the Boreal Zone

Climate/growth relationships were indexed to include references that went beyond strictly climatic information or strictly biomass information. This indexing category is the most important one in the report because it relates most directly to the project's main objective, which was to determine quantitative and qualitative relationships between key climatic parameters and measures of forest biomass.

In relation to climate/growth relationships, references were indexed according to

a) direct relationships between plant growth and climatic variables;

b) indirect influences of climate upon biomass accumulation as a result of climatic controls over organic matter losses to insects, fire, or other growth-controlling factors;

c) microclimatic influences upon plant growth that override macroclimatic or mesoclimatic levels of control;

d) latitudinal gradients of growth rates were indexed separately, although such gradients are in many cases simply a reflection of gradients of temperature, precipitation, or growing season lengths; information on altitudinal gradients of growth was indexed together with latitudinal gradients.

4.5 Climatic Change in the Boreal Zone

A distinction was made between climatic change and climatic variation. **Climatic change,** as an indexing category, groups references that deal with climatic reconstruction for periods that pre-date meteorological records. This group of references deals with hypotheses about long-term climatic changes and a variety of methods for paleoclimatological studies, including dendrochronology and various other forms of proxy data.

The topics included in the indexing term **climatic variation** are outlined in Section 4.6.

4.6 Climatic Variation Within the Boreal Zone

For purposes of this report, **climatic variation** refers to annual or short-term variations in climatic parameters, of sufficiently recent occurrence to be based on meteorological records. Regional and temporal variations were indexed separately. The spatial variations implied by the word 'regional' include both latitudinal and altitudinal variations. Temporal variations were considered to include information on documented climatic cycles as well as noncyclic climatic events. Because temperature and precipitation appear to be the two broad climatic parameters of most physiological relevance to forest growth, references that provided specific information on temperature or precipitation variations, whether these differences are temporal or spatial, were indexed separately to aid index identification of literature sources that deal specifically with temperature or precipitation.

4.7 Growing Season of the Boreal Zone

Length of growing season, degree-day totals during the growing season, and the presence or absence of killing frosts during the growing season were the main subjects indexed under this heading. Data on evapotranspiration during the growing season were indexed as **Climate (precipitation)**, under item 2.2 of Table 4.

4.8 Tree-line Studies

Although relatively little information on forest biomass was derived from the literature on tree-line studies, a number of such references were reviewed because they provided insights into climatic change and information on physiological or ecological limits to growth processes at the edges of the boreal zone. Information from tree-line studies was indexed separately according to growth data for tree species near the tree-line and climatic data of tree-line areas.

5. ANNOTATED BIBLIOGRAPHY OF REFERENCES ON CLIMATE/ BIOMASS RELATIONSHIPS IN THE BOREAL FOREST ZONE

5.1 Format of Annotated References

Each annotated reference in this bibliography contains six numbered parts:

1. Author(s)
2. Date of publication
3. Title of article
4. Identification of publication that contains the article
5. a. Geographic index
   b. Species index
   c. Subject index
6. Annotation of key information

Annotations of selected references range from a few sentences to several pages, but most are one or

two pages in length. In some cases the author's abstract was used, with additions and explanations as required. Emphasis was on results and conclusions rather than on methods of study, and the focus was on information about relationships between climatic parameters and growth rates of boreal tree species. Ouantitative data in table form and in regression equation form have been included in many annotations. Graphs, maps, or other pictorial methods of portraying biomass data or climate-biomass relationships were not included.

For most references, tree or stand measurements of height, diameter, volume, or biomass have been converted to metric units if they were not so expressed in the original publication. Such conversion involved rounding off figures in some cases, with the result that additions of rows or columns do not always yield sums that are exact metric equivalents of originally published totals. Where conversions were performed for standing crop data, tonnes per hectare (t/ha) was the most commonly used unit of measure[2]. If authors originally recorded standing crop data as grams per square metre (g/m^2) or as kilograms per hectare (kg/ha) these units were not converted to tonnes per hectare in the annotated summary of the article. When original data were presented as centners, conversions to kilograms or tonnes were performed (1 centner = 100 kilograms).

Well-known metric units were abbreviated in the text and in tables; less commonly used units, such as langleys, kilolangleys, or centners, were generally not abbreviated, and uncommon units of measure, such as Pg (1 Pg = 10^{15} g) or Tg (1 Tg = 10^{12} g), were defined if they were used in the annotation. Although some literature provided data in terms of energy content (caloric values), these data were not included in annotations. Unless standing crop data were specified to be on a fresh weight basis, all recorded values should be considered to be ovendry weights.

The 329 references contained in this bibliography are listed alphabetically by author. Where an author's first name was recorded in the original publication, the first name was used in the first line of the annotated reference; if initials were used in place of first names in the original publication then initials were used in this bibliography. Some Russian surnames are inconsistently translated, such as the alternative spellings for Bazilevich/Bazilvec or Grigorjev/Grigor'yev, and in such cases the spelling contained in any specific reference was maintained.

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2. Common units of biomass based on dry weight are as follows:
   1 g/m^2 (grams per square metre)
   = 10 kg/ha (kilograms per hectare)
   = 0.01 t/ha (tonnes per hectare)
   = 1 t/km^2 (tonnes per square kilometre)
   = 8.9 lb/acre (pounds per acre)

Although this bibliography contains one reference dated after 1981 (Meentemeyer et al. 1982), the end of 1981 was the effective cut-off date for this literature review. Approximately 45% of the references date from the 5-year period from 1977 to 1981, and 70% date from the decade that preceded the end of 1981.

The annotated references in this volume are not intended to be read sequentially as one would read a text. The key to efficient retrieval of information from this bibliography is use of the circumboreal geographic index, map index, boreal forest section index, boreal tree species index, or subject index at the end of this report.

5.2 Indexing System

The basic bibliographic information (author, date, title of article, identity of publication) for each annotated reference is followed by a three-part indexing system: geographic index; species index; and subject index. In the next section of this report, annotated information was reduced to allow two typed pages to appear on each printed page. Many individual pages contain two separate references and in a few cases a given indexing term applies to both references on a page. Readers are cautioned, therefore, to check both halves of a printed page when using a page number from any of the index categories. Criteria used to construct the three indexes are outlined below.

5.2.1 Geographic index

Under the geographic index, every reference is first identified according to the country or countries from which the data were derived. For references from locations outside North America, only the country is listed in the geographic index, with no further indexing according to ecological zone or map subdivision. For references from United States study sites, only the state is identified with no indication of ecological zone or map subdivision. For references that deal with Canada, the second part of the geographic index identifies the source areas for the data by reference to map sheet(s) of the 1:1 000 000 International Map of the World series.[3] Index numbers for the 48 map sheets that cover the Canadian area of interest for this bibliography are listed in Figure 1. For references from Canadian study sites, the third part of the geographic index is a listing by province, followed by index terms that identify the data sources according to the 45 forest sections of the Boreal Forest Region (Rowe 1972).

5.2.2 Species index

When possible, biomass and growth data were identified by individual tree species in Part 5b of each annotation. Where data were presented according to forest types or particular layers of vegetation (shrub, herb, moss, lichen) within

3. Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa.

boreal forest types, the author's terminology for forest types was adopted within the annotation, but no index was prepared on the basis of forest type names.

The main species included in the boreal tree species index at the end of this volume are as follows:

Alder - **Alnus** spp.
Aspen, trembling - **Populus tremuloides** in North America; **Populus tremula** in Europe
Aspen, largetooth - **Populus grandidentata**
Birch - **Betula verrucosa, Betula japonica**, other unspecified **Betula** spp.
Birch, white - **Betula papyrifera**
Fir, balsam - **Abies balsamea**
Larch - **Larix laricina** in North America; **Larix sibirica, Larix sukatschevii, Larix kurilensis, Larix dahurica, Larix europea** in Europe
Pine - Unspecified **Pinus** spp. in Europe
Pine, jack - **Pinus banksiana**
Pine, lodgepole - **Pinus contorta**
Pine, red - **Pinus resinosa**
Pine, Scots - **Pinus sylvestris**
Poplar, balsam - **Populus balsamifera**
Spruce - **Picea excelsa** and other unspecified **Picea** spp. in Europe
Spruce, black - **Picea mariana**
Spruce, Norway - **Picea abies**
Spruce, white - **Picea glauca**
Willow - **Salix** spp.

5.2.3 Subject index

As outlined in sections 4.2 to 4.8, Part 5c of each reference lists indexing terms that identify the annotated information according to 25 subject headings listed in Table 4.

ANNOTATED REFERENCES

ADAMENKO, V.N

2. 1963

3. On the similarity in the growth of trees in northern Scandinavia and in the polar Ural Mountains.

4. Journal of Glaciology 4:449-451

5. a. Sweden; U.S.S.R.

b. nil

c. Climate change (dendrochronology)

6. The author's observation that tree rings serve as an indicator of ablation conditions on glaciers in the Ural Mountains led to a comparison of tree rings in northern Scandinavia and in the polar Urals. On the basis of 30-year running mean dendrochronological indices, there is a strong resemblance between the growth of conifers in Scandinavia and the polar Urals. This resemblance shows that both in the polar Urals and in northern Scandinavia there is a close similarity between the thermal conditions of glacial ablation and their secular changes. This resemblance can only be explained by the fact that the perennial changes during tree-ring growth are due to large-scale changes in the atmospheric circulation and even, perhaps, planetary ones.

On the basis of a preliminary analysis, the most favourable conditions hastening tree-ring growth in the polar Urals are likely to occur during the periods when the northern periphery of the areas of high pressure, which stabilize themselves over eastern Europe, are repeatedly situated over the polar Urals, and when the northern margin of the Arctic Ocean is also under the influence of cyclonic centres. Delay in the growth of trees in Scandinavia, compared with that in the polar Urals, can be explained by the same delay observed in the frequency trends of the anticyclonic situations in western and central Europe, compared with those in eastern Europe, but this problem requires special study.

The author concluded that in the 18th century the conditions for tree-ring growth (and perhaps glacial ablation) in the polar Urals and in Scandinavia were more favourable than those of the 19th century. In the present century, beginning in the 1920's, active glacier ablation is proceeding; these phenomena are connected both with changes in the general atmospheric circulation and with the 20th century climatic warming observed by other authors.

1. ADAMS, J.A.S., K.S.M. MANTOVANI and L.L. LUNDELL

2. 1977

3. Wood versus fossil fuel as a source of excess carbon dioxide in the atmosphere: a preliminary report.

4. Science 196:54-56

5. a. Northern hemisphere

b. nil

c. Climate (carbon dioxide levels)

6. A preliminary reexamination of the scant data available on deforestation indicates that there has been a substantial underestimation of the net CO_2 produced from deforestation.

The authors estimated that, excluding the commercial forest products industry in the United States, some 0.2 metric tons of carbon wood are lost annually per capita in clearing and noncommercial activities. If one takes this upper limit of 0.2 tons per capita and assumes that the managed forests in the United States are near a steady-state condition (plantings equal cutting plus losses), it would appear that the carbon from net wood loss in the United States is at most only 2% or so of that from fossil fuels. Such, however, is not the case in most of the world.

For Brazil as a whole, including the large-scale forest clearing in the Amazon, the estimate of an annual consumption of 3.0 net tons of carbon in wood per capita from clearing must be considered a minimum that may be too low by as much as an order of magnitude. The replacement estimate for Brazil of 1.0 tons per capita per year must be considered a maximum, and hence the ratio of the net wood loss to the fossil fuel loss of 5.0 must be considered a minimum.

In order that an individual can obtain the needed 2,000 kcal of energy from food per day, it is necessary in much of the world to consume 3 to kg of wood per capita per day to cook the rice, wheat, and other foods and also to provide the heat for modest amounts of metalworking, ceramic firing, distilling, and other similar cottage industries. Although the net global loss is difficult to estimate, the net loss in Brazil alone suggests that the minimum global loss is 0.1 tons of carbon from wood per capita per year. The authors suggest that the net global loss is between 0.1 and 1.0 tons of carbon from wood per capita per year. It follows that the CO_2 produced from net deforestation or the draining of the "cellulose reservoir" is essentially equal to the CO_2 that has been produced by the combustion of fossil fuel throughout this century.

The authors' model implies that, without any concurrent deforestation in this century, the buildup of atmospheric CO_2 in the atmosphere would have been very minor. One may obtain refined estimates of the amounts of

Continued

Adams, J.A.S., M.S.M. Mantovani and L.L. Lundell. 1977. Continued

CO_2 released to the atmosphere by the burning of wood in the past century by analyzing certain polycyclic aromatic compounds contained in glacier ice or sediments. Polycyclic aromatic hydrocarbons formed during nonindustrial burning of wood are distinct from those formed by either living organisms or the burning of fossil fuel; hence, they may provide a useful molecular tracer.

The authors stress the need for reexamination of the quantitative aspects of net deforestation and wood burning as they affect the amount of CO_2 in the atmosphere and atmospheric inputs and outputs.

1. AHTI, TEUVO

2. 1961

3. The open boreal woodland subzone and its relation to reindeer husbandry.

4. Archiva Societas zoologica-botanica Fennica Vanamo 16 (Supplement): 91-93

5. a. Finland

   b. nil

   c. Climate/growth (direct relationships)

6. Although this article contains no biomass data on boreal species, the author refers to climatic characteristics of the portion of the boreal forest dominated by lichen woodland.

About one-third of Finland, most of the northern part of the country, belongs to the main circumpolar subdivision of the boreal forest belt, which is called the open boreal woodland subzone or northern taiga. Throughout most of this subzone lichen woodland is the characteristic cover type in nonswampy sites. Hare (1954) indicated that the northern limit of the subzone generally lies close to the Thornthwaite thermal efficiency isopleths of 33 to 35 cm, while its southern limit is near the isopleths of 41 to 43 cm. A close relationship between the abundance of lichen woodlands and the above-mentioned climatic limits in Finland is obvious. However, this phenomenon has not received much attention from the Fennoscandian botanists. This is due to the fact that the open boreal woodland subzone in northwestern Europe is marginal in character and thus only poorly developed and less conspicuous than in the corresponding parts of Canada and the U.S.S.R. Although the subzone may be said to occur in oceanic areas also, the lichen woodlands are not present along the Finland coast. In Finland, this oceanic influence is seen in the small frequency of excessively drained sites suitable for the development of lichen woodlands. In the coniferous zone of Finland they cover only 5 to 20% of the productive forest land.

1. **AHTI, Teuvo**

2. 1977

3. Lichens of the boreal coniferous zone.

4. IN: M.R.D. Seaward, Editor, Lichen ecology, Academic Press, p. 145-181.

5. a. Northern hemisphere

   b. Nil

   c. Biomass (moss/lichen)

6. This article deals mainly with vegetational features of lichen communities in the circumpolar band of boreal vegetation. Limited lichen biomass data are summarized, mainly from the works of other investigators, as outlined below.

Fire is a very important ecological factor all over the boreal forest, especially in the continental areas. In lichen forests, fires are particularly destructive to dry vegetation. The following pattern of succession after fire has been established over almost all the boreal forest:

1. Bare soil stage, 1 to 3 yr after fire.

2. Crustose lichen stage, 3 to 10 yr after fire; **Lecidea oligotropha, L. uliginosa** and **L. granulosa** dominant.

3. Cup lichen stage 10 to 50 yr after fire; **Cladonia cornuta** var. **cornuta, C. gracilis** var. **dilatata, C. crispa, C. gonecha** dominant.

4. First reindeer lichen stage, 50 to 120 yr after fire; **Cladonia mitis, C. arbuscula, C. rangiferina** and **C. uncialis** dominant.

5. Second reindeer lichen stage, 120 or more years after fire; **Cladonia stellaris** dominant.

Since the lichen woodlands are important winter ranges to both domesticated reindeer and wild reindeer or caribou, the biomass of these communities are also fairly well known. In the **Cladonia stellaris** stage the standing crop of palatable reindeer lichen may exceed 3,000 kg/ha and form as much as 50% of the total above-ground vegetation biomass, but the annual growth of such an "overmature" lichen land may be negligible. The most productive lichen-rich forest for the reindeer industry has only a 4 to 6 cm tall lichen stand, which may support about 500 to 1,500 kg/ha of forage, with an annual growth of 50 to 160 kg/ha.

Continued ...

The productivity of epiphytic lichens has been studied mainly in connection with reindeer and caribou range surveys. In northern boreal Saskatchewan, Scotter (1962) reported 145 to 231 kg/ha of lichens (air-dry) on mature **Picea mariana** and 88 to 472 kg/ha on **Pinus banksiana**. On **Picea** more than 50% of the lichen loads occurred within 3 m above ground (within reach of caribou) while on **Pinus** only 20% occurred within this area. Most of the epiphytic lichen biomass consisted of **Alectoria jubata, Evernia mesomorpha** and **Usnea hirta.** In Kamchatka, other investigations recorded 220 kg/ha of lichens on **Betula ermanii** and in Estonia 402 to 480 kg/ha on **Pinus sylvestris.**

1. AJTAY, G.L., P. KETNER and P. DUVIGNEAUD

2. 1979

3. Terrestrial primary production and phytomass.

4. IN: B. Bolin, E.T. Degens, S. Kempe and P. Ketner, Editors, Scope 13, The global carbon cycle, John Wiley & Sons, Toronto. p. 129-181

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb, moss/lichen), Climate (carbon dioxide levels), Climate/growth (latitude)

6. The magnitude of the world's terrestrial production and phytomass can be estimated in two different ways, either by classifying the biosphere into ecosystem types and estimating averages and total values for each of these, or by modelling the effects of environmental factors on productivity and phytomass and integrating the results of the model for the earth surfaces. The first approach is used in this study. Details on the second approach can be found in publications by Lieth. Numerous estimates have already been made of the total world net primary production. Whittaker and Likens (1975) provided recent estimates of total terrestrial production at 53 x 10^{15} g C/yr (117.5 x 10^{15} g dry matter). The highest estimate of production was suggested by Bazilevich and co-workers who give 72 x 10^{15} g C/yr for total terrestrial production.

Total net primary production of terrestrial biota was estimated by the authors to be 60 x 10^{15} g C/yr produced by 560 x 10^{15} g C contained in living phytomass. The total amount of standing dead organic matter is estimated as 30 x 10^{15} g C, and the total amount of litter as 60 x 10^{15} g C. The value of total litterfall is estimated to be between 45 and 50 x 10^{15} g C. Soil organic matter amounts to 1600 to 2000 x 10^{15} g C, a value higher than most of the earlier estimates.

Estimates of net primary production and other characteristics related to productivity are shown in the table on the following page for the earth's boreal zone and for the total continental area and total marine area of the earth.

Continued ...

	Total boreal forest	Total continental area	Total marine area
Area (10^{12} m^2)	12.0	149	361
Net Primary production, dry matter			
Normal range (g/m^2/yr)	400-2000	-	-
Mean (g/m^2/yr)	800	782	155
Total (10^{15} g/yr)	9.6	117.5	55.0
Total biomass, dry matter			
Normal range (10^3 g/m^2)	6-40	-	-
Mean (10^3 g/m^2)	20	12.2	0.01
Total (10^{15} g)	240	1837	3.9
Litter biomass (10^{15} g)	48.0	111	-
Animal consumption (10^{12} g/yr)	380	7810	20230
Animal production (10^{12} g/yr)	38	909	3025
Animal biomass (10^{12} g)	57	1005	997

A more detailed breakdown of ecosystem types, which recognized two subdivisions within the boreal forest, resulted in the estimates of surface areas, net primary productivity and phytomass shown in the table below. Carbon was estimated to be 45% of dry weight biomass.

	Closed boreal forest	Open boreal forest
Surface area (10^{12} m^2)	6.5	2.5
Net primary production, dry matter (g/m^2/yr)	850	650
Total production, dry matter (10^{15} g/yr)	5.53	1.63
Total production, carbon (10^{15} g/yr)	2.49	0.73
Living phytomass, dry matter (10^3 g/m^2)	25	17
Total dry matter in living phytomass (10^{15} g)	162.5	42.5
Total carbon in living phytomass (10^{15} g)	73.13	19.12

The dead organic matter in land biota consists of the total amount of organic matter incorporated in trees and shrubs that are dead but still standing, dead organs (dry but not yet fallen branches of trees and shrubs, dry stems of herbaceous plants), the matter accumulated as litter, and the organic matter accumulated in the soil as humus. The data are too scanty to make any extrapolation, but the authors assumed that total standing dead organic matter, on average, equals about 5% of the total living phytomass, or about 60 x 10^{15} g dry matter. With an average carbon content of 50%, this would mean 30 x 10^{15} g C, a value which is much lower than that given by Bazilevich and co-workers for standing dead and dry trees, namely 75 x 10^{15} g C.

Continued ...

The authors noted that from published data it is not always clear which definition of litter was adopted or whether litter included standing dead material. Generally, litter accumulation takes place in cool areas, in biomes such as scrub tundra, taiga, and temperate forests, and can amount to 8000 g/m^2, 3000 to 4500 g/m^2, and 1500 g/m^2, respectively, in these biomes. The highest values, more than 10,000 g/m^2, were found for temperate coniferous forests. In wet tropical lands, where mean temperatures are above 30° C, litter is destroyed faster than it is supplied. Between 25 and 30° C, litter supply and decomposition are about equal.

An important part of the biological cycle is litterfall, which is the flux from living to dead matter. Litterfall can be defined as the organic matter incorporated in all plant elements of the above-ground and underground parts of the community that die annually, and in plants or parts of plants that die in the course of aging or natural thinning.

In steady-state ecosystems, total litterfall should equal total net production, and often the same value is taken for total litterfall as for net primary production when a model of the carbon cycle is prepared. On the other hand, part of the net production is consumed by herbivores or lost through other causes, so that total litterfall should be less than net production.

Estimated litterfall and litter in two subdivisions of the boreal forest are as follows, using a conversion factor from dry matter to carbon of 0.45 for litterfall and 0.50 for litter.

	Closed boreal forest	Open boreal forest
Surface area (10^{12} m^2)	6.5	2.5
Litterfall, dry matter ($g/m^2/yr$)	600	550
Total dry matter in litterfall (10^{15} g)	3.9	1.4
Total carbon in litterfall (10^{15} g)	1.8	0.6
Litter, dry matter (g/m^2)	3500*	
Total dry matter in litter (10^{15} g)	31.5*	
Total carbon in litter (10^{15} g)	15.8*	

* Closed and open boreal forest combined.

Continued ...

The authors' estimates of soil carbon content in the boreal forest and for the total land area are shown in the following table.

	Boreal forest	Total land area
Area (10^{12} m^2)	9	149.3
Organic soil carbon to a depth of 1 m (10^3 g/m^2)	15	-
Total carbon (10^{15} g)	135	1635.6

The authors' estimate of total soil carbon suggests that earlier estimates of soil organic carbon have been too low. Humus represents a much larger reservoir than the carbon fixed in dead organic matter such as litter, standing dead or dead wood, and is also much larger than the amount of carbon in living phytomass. However, the distinction between the various components is gradual and, because of this, an estimate of each component remains difficult. The study of dead organic matter, including humus, has been neglected in the study of biological productivity of natural ecosystems and needs further attention, particularly as man's impact on soil rbon is increasing; through increased decomposition as a result of clearing and cultivation, soil carbon content is decreasing in many parts of the world.

There are marked differences between forest ecosystems of different climatic zones when comparisons are made of the relative amounts of carbon accumulated in abiotic (soil, litter) and biotic (wood, leaves) components of ecosystems. In temperate and cold climates, the accumulation takes place in the form of humus, and in tropical forests the largest amount of carbon is found in the form of living phytomass, mainly wood, and only a small amount in the form of litter. Consequently, the clearing of tropical forests diminishes accumulated carbon more rapidly than in temperate forests. Moreover, an extra diminishing of carbon takes place through increased decomposition of soil organic matter after clearing, particularly in tropical areas. The biogeochemical consequences concern not only the carbon cycle, but also the more indirect contribution of phytc as reduction and erosion to the increased transfer of nutrients from land surfaces to rivers nd oceans. The diminishing vegetation cover, followed by erosion of topsoil, will ultimately lead to a noticeable decrease in productivity, as water conditions and nutrient content are reduced to levels no longer optimal for photosynthesis.

1. ALBAN, David H., Donald A. PERALA and Bryce E. SCHLAEGEL

2. 1978

3. Biomass and nutrient distribution in aspen, pine, and spruce stands on the same soil type in Minnesota.

4. Canadian Journal of Forest Research 8:290-299

5. a. Minnesota

   b. Aspen, Jack pine, Red pine, White spruce

   c. Biomass (tree, shrub/herb)

6. The objective of this study was to quantify nutrient drain as a result of timber harvesting by examination of biomass and nutrient distribution within four forest types on the same soil in Minnesota. The study area was located in north-central Minnesota (47 20 N, 94 30 W) where the mean January temperature is -14° C and the mean July temperature is 20° C. Annual precipitation is 61 cm, half of which falls during the growing season.

Characteristics of the stands sampled are summarized in Table 1 and standing crop data are summarized in Tables 2 and 3. Considering overstory vegetation, understory vegetation and soils combined, total organic matter estimates were: aspen, 285 t/ha; spruce, 289 t/ha; red pine 356 t/ha; and jack pine 278 t/ha.

Table 1. Stand characteristics

Stand	No trees per hectare	Mean height m	Basal area, m^2/ha	Volume inside bark, m^3/ha	Site index (50 yr), m
aspen					
aspen	1334	20.3	34.7	286	22.9
other species	1655	11.0	7.0	39	--
white spruce	2187	14.4	41.1	256	18.3
red pine	1780	17.6	51.9	408	20.7
jack pine	1580	18.4	35.1	263	21.3

continued ...

Table 2. Organic matter (t/ha) in overstory vegetation in Minnesota stands sampled.

Stand	Foliage	Branches	Bole bark	Bole wood	Root + stump
aspen	3.6	16.6	27.6	119	38
spruce	17.4	34.6	10.8	88	34
red pine	13.8	25.2	13.4	147	44
jack pine	5.5	23.4	12.4	106	28

Table 3. Organic matter (t/ha) in understory vegetation and in soils in Minnesota stands sampled.

	Vegetation Understory		Soil		
			Forest	Mineral Soil	
Stand	Herbs	Shrubs	floor	0-10 cm	10-36 cm
aspen	0.09	3.1	27	35	15
spruce	0.02	0.1	33	49	22
red pine	0.03	4.4	30	58	20
jack pine	0.04	2.9	33	48	19

Total tree biomass was greatest for red pine followed by aspen, spruce and jack pine. Nutrient weights (N, P, K, Ca, Mg) in the trees were greatest in aspen followed generally by spruce, red pine, and jack pine. Particularly large proportions of biomass and nutrients were found in aspen bark and spruce foliage and branches. Understory biomass contributed less than 1.2% of the total organic matter in the vegetation-soil complex but contributed up to 5.0% of the nutrients. Exchangeable Ca in the surface soil was much lower under aspen and spruce than under the pines. No significant soil differences between species were detected below 36 cm. In general, total above-ground tree removal places a 2 to 11 times greater drain on the site, depending upon species and trient, than if only bole wood is removed.

Calcium appears to be a key nutrient in forest ecosystems because of its large accumulation in comparison with many agricultural crops. Aspen and spruce stands have more Ca in their biomass and less in their surface soil than the pines. The lower soil Ca levels under aspen and spruce result in lower pH values under these species. The fact that forest crops take up large amounts of Ca in relation to agricultural crops suggests that micronutrients need to be examined to see if some of these might also be used in large amounts by forests.

1. ALBREKTSON, Arne

2. 1980

3. Tallens biomassa, storlek - utveckling - uppskattningsmetoder. [Biomass of Scots pine (Pinus sylvestris L.) amount - development - methods of mensuration].

4. The Swedish University of Agricultural Sciences, Department of Silviculture, Umeå, Sweden. Report No. 2, 189 p

5. a. Sweden

   b. Scots pine

   c. Biomass (tree)

6. Tree biomass was investigated from 1974 to 1977 in 189 sample trees from 21 sites. The investigations were made in central Sweden and the stands form an age succession. Sites were characterized by dry and sandy soil, but mesic sites, one site on peatland and fertilized sites were also represented.

An analysis of the investigated stands shows that total biomass increases with age. The increase is mostly a result of accumulatio of stem, stump and coarse root biomass. The amounts of branch axes and needles seem to be almost independent of stand age. Analysis of biomass components, as a proportion of stem biomass showed that the proportion of biomass as stumps and coarse roots remained approximately constant over age, at 7% of stem volume and 10% of stem volume, respectively. The relation of needles and branch axes to stems decreased with age.

The author's study showed that allocation of production in the tree changed with tree growth. Production of needles and branch axes per needle unit decreased with tree height, and production of stems, stumps and coarse roots increased at first but decreased at moderate height. Diameter growth tended to influence allocation in the opposite direction. Diameter and length of the mean branch were positively correlated with crown weight but negatively with tree height. Crown length and number of branches were positively correlated with both crown weight and tree height.

1. ALBREKTSON, A.

2. 1980

3. Relations between tree biomass fractions and conventional silvicultural measurements.

4. IN: T. Persson, Editor, Structure and function of northern coniferous forests - an ecosystem study. Ecological Bulletins (Stockholm) 32:315-327

5. a. Sweden

   b. Scots pine

   c. Biomass (tree)

6. Tree biomass fractions were investigated in Scots pine stands of different age classes at several sites in central Sweden (Jädraås, Ytterhogdal and Lisselbo, ranging from 60 28 N to 62 10 N and from 14 50 E to 16 57 E). Biomass and development of biomass were analyzed, and methods of calculating the amount of biomass by non-destructive methods were discussed. The author also described changes in tree biomass fractions during stand development.

The youngest stands, aged 9 to 14 yr, had a large proportion of their biomass bound to living branches. Stem, stump and coarse root biomass increment continues throughout a very long period but slows down when the stands reach maturity. Production of stem, stump and coarse root biomass corresponded to the overall biomass increase since all production is accumulated. Branch and needle biomass and needle production seem to increase very rapidly in young stands and culminate at a stand age of about 30 yr. After this age there is a slight reduction in branch and needle biomass and needle production.

Total biomass (excluding roots under 30 mm diameter) ranged from 16,537 kg/ha (dry weight) in a 12-yr stand to 146,768 kg/ha in a stand 84 yr old.

1. ALEMDAG, I.S. and K.W. HORTON

2. 1981

3. Single-tree equations for estimating biomass of trembling aspen, large tooth aspen and white birch in Ontario.

4. The Forestry Chronicle 57:169-173

5. a. Canada; Index maps NN-16, NN-17; Ontario; 8.7, 8.9

   b. Aspen, white birch

   c. Biomass (tree)

6. Oven dry above-ground biomass of single trees of trembling aspen, large tooth aspen and white birch in the Great Lakes - St. Lawrence and boreal forest regions in Ontario was studied in relation to stem dimensions. Mass equations for tree components based on diameter at breast height outside bark and tree height were developed. The study covered three locations in the Great Lakes - St. Lawrence forest region, between Chalk River and Haliburton, and two broad areas near Kirkland Lake and Nipigon, representing the eastern and western portions of the boreal forest region in Ontario.

The table below lists regression data on the prediction of oven dry above-ground biomass for trees of 5.1 cm dbhob and larger, in the boreal region, using the model $OM = b_1 \times (dbhob)^2 \times h$, where OM = oven dry above-ground biomass in kilograms, dbhob = diameter at breast height outside bark in centimetres and h = tree height in metres.

	b_1	r^2	SEE%
	Trembling Aspen (n=96)		
Stem wood	1.4748×10^{-2}	0.963	18.7
Stem bark	2.7476×10^{-3}	0.931	27.8
Live branches	2.1939×10^{-3}	0.774	59.8
Twigs and leaves	5.7001×10^{-4}	0.683	62.2
Whole tree	2.0259×10^{-2}	0.964	18.8
	White Birch (n=67)		
Stem wood	1.6001×10^{-2}	0.973	12.1
Stem bark	2.7467×10^{-3}	0.609	58.6
Live branches	2.5581×10^{-3}	0.726	50.3
Twigs and leaves	6.8510×10^{-4}	0.678	44.3
Whole tree	2.1991×10^{-2}	0.970	13.0

Continued ...

For trees 0.1 cm to 5.0 cm dbhob, the above-ground oven dry mass was derived from the following equation, which combined all species in both regions:

$$OM = 0.030 + 0.021107 \times (dbhob)^2 \times h$$

The proportions of the oven dry mass of tree components in relation to stem wood and the whole tree show that stem wood constitutes 67 to 73% of the total mass, stem bark 12 to 16%, live branches 10 to 17%, and twigs and leaves 2 to 4%. Thus, the stem with bark represents the major part (79 to 85%).

1. ALEXANDROVA, Vera D.

2. 1970

3. The vegetation of the tundra zones in the USSR and data about its productivity.

4. IN: W.A. Fuller and P.C. Kevan, Editors, Proceedings of the Conference on Productivity and Conservation in Northern Circumpolar Lands, IUCN Publications New Series, Morges, Switzerland, No. 16. p. 93-114

5. a. U.S.S.R.

   b. nil

   c. Biomass (tree, shrub/herb, moss/lichen)

6. Although this review dealt mainly with tundra biomass estimates, one of the summary tables contains data on above-ground biomass for tundra woodlands and for open forests at the northern edges of U.S.S.R. boreal forests. The table below lists these biomass estimates by separate vegetation layers.

Vegetation layer	Above-ground biomass dry wt. (kg/ha) tundra woodland	open boreal forest
Bryophytes	1,370	1,500
Fruticose lichens	420	300
Sedges	190	220
Grasses	5	-
Herbs	25	30
Arctic dwarf shrubs	-	-
Subarctic dwarf shrubs	560	620
Dwarf birch	710	830
Shrub willows	340	240
Trees	3,650	8,230
Total	7,270	11,970

1. ALLEN, Richard

2. 1980

3. The impact of CO_2 on world climate.

4. Environment 22(10):6-13,37-38

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels), Climatic change (hypotheses)

6. There are some 700 billion tons of carbon in the atmosphere, and this is but a small proportion of the total carbon continuously transferred among the principal "reservoirs" which comprise the global biogeochemical cycle - the carbonate sediments of the Earth's crust, the carbonate ions of the oceans, and the organic compounds of world biomass humus.

The world's biota contains approximately 800 billion tons of organic carbon. Ninety percent of this is contained within the world's forests, and 42% is contained within tropical forests. An additional 1,000 to 3,000 billion tons of carbon are held in the organic matter of soil humus. It has been estimated that the destruction of the world's forests, particularly in the tropics, may be releasing as much CO_2 to the atmosphere as the combustion of fossil fuels. However, the range of uncertainty here is great and the actual biotic release may vary by as much as a factor of four.

The world's forests contain three times as much carbon as that contained in atmospheric CO_2. Seasonal variations in the amount of CO_2 in the atmosphere due to the photosynthetic activities of plants are responsible for an annual fluctuation in atmospheric CO_2 content between 5 and 15 ppm, or as much as 7% of the total atmospheric increase of CO_2 since 1958. Some studies suggest that increased atmospheric concentrations of CO_2 could actually stimulate global biotic photosynthesis and thus lead to enough increased photosynthetic absorption of CO_2 to at least partially compensate for man-made releases. The author states that whether this hypothesis is valid or not, it is irrelevant as long as the world's forests are being destroyed at the current rapid rate. Rather, it points up the need for the preservation of forests and their proper management in order to reduce CO_2 release and to maintain a potentially large CO_2 reservoir.

The increase of CO_2 in the atmosphere produced by human activity raises the temperature of the earth above what it would naturally be. But atmospheric CO_2 is not the only factor determining whether our climate will be warmer or cooler. From 1940 to 1970 there was a cooling trend which most scientists credit to natural forces or the increasing amount

Continued ...

Allen, R. 1980. Continued

of dust mankind has been putting into the atmosphere and the greater albedo or reflectivity that this causes. Based on studies of sunspot activity, there have also been predictions of a new natural cooling trend beginning in the 1980's and reaching its lowest point during the 1990's. However, the consensus of scientific opinion continues to be that, by burning fossil fuels and cutting down the forests, we are ensuring that the average global temperature will be significantly higher by the middle of the next century than it is today, with all the environmental consequences this warming will entail.

The author concludes that because the energy policies of the less developed nations are not yet firmly established, a unique opportunity may exist to assist these countries in developing a policy that minimizes the use of those fuels that release large amounts of CO_2, a policy that places as much emphasis as possible on alternative energy sources. At the very least it is essential that we begin sharing information about the CO_2 problem with the scientific and political leaders of these countries. Because biomass destruction is currently a net source of CO_2 and because photosynthetic absorption could some day play a pivotal role in CO_2 reduction, the destruction of the world's forests, particularly in the tropical and subtropical regions, must be minimized.

1. AMUNDSON, Donna C. and H.E. WRIGHT Jr.

2. 1979

3. Forest changes in Minnesota at the end of the Pleistocene.

4. Ecological Monographs 49:1-16

5. a. Minnesota

   b. Nil

   c. Climatic change (hypotheses, proxy data)

6. According to studies by Bryson and co-workers, the southern limit of the boreal spruce forest today follows closely the mean winter position of the polar front. The area to the south is dominated today by dry Pacific air that extends east in the summer to the midwestern states, and by warm Atlantic air in the eastern states. This general relation between boreal forest and air-mass frequency presumably prevailed in the late Pleistocene, but with different dimensions. As the mean frontal positions of arctic air moved north with climatic change and retreat of the ice sheet, the climate was no longer suitable for the regeneration of spruce trees, and trees from more temperate regions expanded at the expense of spruce.

In northeastern Minnesota during the interval of climatic warming, elm was an especially aggressive migrant. It not only followed but invaded the retreating spruce forest, along with jack pine, which was moving in from the east. It is thought that elm and jack pine may have reached the tundra border. After 10,000 BP the tundra fringe in front of the retreating ice sheet was pinched out by rapid northward expansion of this closed mixed boreal-temperate forest. For more than 1,000 yr in northeastern Minnesota, elm maintained a more significant presence than it does today in that region, along with oak and other hardwoods. About 8,800 BP these hardwoods decreased rather abruptly as pine increased, and the authors suggest that another nonclimatic factor, the immigration of red pine, may have been the major factor in bringing about the change. The authors stressed that the modern conifer forests of Canada provide no perfect analogues for the late-Pleistocene spruce forest of Minnesota nor for the pine or hardwood forests that succeeded it.

In summary, charcoal counts provide no support for the hypothesis that increased fire incidence explains the forest transformation from spruce to pine. Climatic change must instead be the primary cause. As the ice sheet withdrew, its influence decreased. Differential rates of tree immigration as well as progressive leaching of upland soils may have been additional factors affecting changes in forest composition.

1. ANDREWS, J.T., P.T. DAVIS, W.N. MODE, B. NICHOLS and S.R. SHORT

2. 1981

3. Relative departures in July temperatures in northern Canada for the past 6,000 yr.

4. Nature 289:164-167

5. a. Canada; Index map NP-13/14, District of Keewatin; B.32

   b. Nil

   c. Climate (temperature), Climatic change (proxy data)

6. There has been concern about recent temperature trends and the future effects of CO_2 concentrations in the atmosphere; but instrumental records only cover a short period and it is essential that proxy data sources, such as pollen spectra from peats and lake sediments, be carefully interpreted as climate records. Several workers have shown statistically significant associations between the modern pollen rain and climatic parameters, an approach that by-passes the recognition of pollen/vegetation units. Statistically defined equations that associate abiotic and biotic elements are called transfer functions. In this study, modern pollen spectra from two transects were used, one trending southwest to northeast from south of treeline to Ennadai Lake, Keewatin, to Clyde River on Baffin Island and one trending south to north from Fort Chimo, Labrador, to Clyde River. The authors only considered the past 6,000 yr so that changes in the pollen spectra primarily reflect climatic stresses rather than migrational histories of the different plant taxa in the pollen record. However, this statement may not be accurate for Labrador where an unusually late migration of conifers several thousand years after deglaciation took place.

Most of the study sites indicated that July temperature departures became, on average, more negative over the last few thousand years. However, this does not preclude rapid climatic changes at certain times. Other studies have indicated that the pollen evidence from Keewatin favoured a series of synchronous step changes in climate across the mainland of arctic Canada, which were superimposed on a general decline in July temperatures. Certain temperature graphs from the authors' work show evidence for similar rapid changes. In particular, the very rapid cooling that began in the late Holocene is notable. At Coppermine Saddle, a temperature drop of about 2° C in 150 yr between 1,400 and 1,250 yr BP is estimated. At Ennadai Lake, Windy Lake and Ublik Pond, July temperatures fell 1 to 2° C close to 2,500 yr BP.

The study area extended across the region covered by one of the main upper atmospheric troughs. As this trough shifts to the east or west, out-of-phase climatic trends may occur, at least on short time scales. Between 5,500 and 6,000 yr ago, in northern Canada, mean July temperatures

Continued ...

departures were, on average, negative. July temperature departures then rose to above average values until 2,500 yr BP, with a reversal between 5,000 and 4,500 yr BP. The highest average departures from July conditions occurred 3,500 to 4,000 yr BP, which apparently represents a Holocene local thermal optimum for the eastern and central Canadian Arctic. Between 3,000-2,500 and 1,000-500 yr BP, the average departures declined steadily and reached a trough in the latter interval.

Nichols' graph of departures of July temperatures from modern values is reproduced by the authors. The major difference between that reconstruction and that by the authors is the interpretation of events after 2,500 yr BP. The authors' reconstruction shows a steady decline to values well below the mean of the nine time-series, whereas Nichols' reconstruction shows less of a decline and, in fact, has temperatures above present between 2,000 and 600 yr BP.

The data indicate that the most useful northern analogue for a 'warm' summer world during the past 6,000 yr is between 3,500 and 4,000 yr ago. July temperatures in the central and eastern Canadian Arctic departed, on average, by about 0.75 standard deviation from the 6,000-yr mean, or about 1° C. Locally, estimated July temperature reconstructions are predicted to have been 2° C to 3° C warmer than at present.

1. ARGUS, George W.

2. 1966

3. Botanical investigations in northeastern Saskatchewan: the subarctic Patterson-Hasbala lakes region.

4. Canadian Field-Naturalist 80:119-143

5. a. Canada; Index map NO-13; Saskatchewan; B.27

   b. Willow

   c. Biomass (shrub/herb)

6. Although this article contains no data on climate or biomass of the boreal forest zone, it makes reference to the fact that woody biomass in some subarctic plant communities can be very tightly packed. The latter characteristic is sometimes referred to in the literature as standing crop density, which is the amount of above ground biomass per unit volume of growing space.

In a study area south of Hasbala Lake, the author recorded a dense thicket of **Salix planifolia**, **Salix serissima** and **Betula glandulosa**, 2 to 2.5 m tall, which grew directly over a small stream. The thicket was so dense that the tops of the shrubs could support the weight of a man. However, the author made no direct measurement of this apparently high standing crop density.

1. ART, H.W. and MARKS, P.L.

2. 1971

3. A summary table of biomass and net annual primary production in forest ecosystems of the world.

4. IN: Forest Biomass Studies, Working group on forest biomass studies Section 25, Growth and Yield, International Union of Forest Research Organizations, University of Maine, Orono, Miscellaneous Publication 132, p. 3-32.

5. a. Northern hemisphere

   b. Balsam fir, pine, spruce

   c. Biomass (tree, shrub/herb)

6. The purpose of this review was to compile published forest biomass and productivity into a relatively simple and standardized presentation. Data were examined for 280 forest stands and those that dealt with boreal species are reproduced below. The figures refer to above-ground portions of trees, shrubs and herbs, except for the data from Baskerville (1965) and Young and Carpenter (1967).

Species (country)	Stand age yr.	Biomass t/ha	Net primary production t/ha/yr	Reference
Abies balsamea (Can)	40-50	133.0-200.1[a]	9.4-12.6	Baskerville (1965)
Picea, N. taiga (USSR)	?	100.0	4.5	Rodin and Bazilevich (1967)
Picea, taiga (USSR)	?	260.0	7.0	Rodin and Bazilevich (1967)
Picea, S. taiga (USSR)	?	330.0	8.5	Rodin and Bazilevich (1967)
Pinus, N. taiga (USSR)	?	80.0	?	Rodin and Bazilevich (1967)
Pinus, S. taiga (USSR)	?	280.0	6.1	Rodin and Bazilevich (1967)
Abies balsamea (USA)	48	77.5[a]	?	Young and Carpenter (1967)
Boreal forest	?	200.0	8.0	Whittaker (1970)

a above-ground portion of trees only

1. **ASTROLOGOVA, L.E.**

2. 1976

3. Biological productivity of the lower layer vegetation in pine bilberry fresh stand of middle taiga subzone, Archangelsk region.

4. Botanicheskii Zhurnal 62:591-596

5. a. U.S.S.R.

   b. Scots pine

   c. Biomass (shrub/herb, moss/lichen)

6. The biomass of the ground (dominated by **Vaccinium myrtillus** and **Vaccinium vitis-idaea**) was measured in one **Pinus sylvestris** stand in the experimental forest of the Archangel Forestry Institute from 1971 to 1974. The total biomass of the forest community was 111.2 t/ha; that of the ground vegetation was 5 t/ha, 44% of which was contributed by herbs and shrubs, and 56% by mosses (mainly **Pleurozium schreberi**). The current annual increment in above-ground biomass of the **Vaccinium** spp. was estimated as 18 to 30% of their total above-ground biomass, contributing about 0.4 t/ha dry matter. The annual growth was completed by the end of July.

1. **BACH, Wilfrid**

2. 1979

3. Impact of increasing atmospheric CO_2 concentrations on global climate: potential consequences and corrective measures.

4. Environment International 2:215-228

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels), Climatic change (hypotheses)

6. Recent evidence from the evaluation of land use statistics, the development of remote sensing techniques, the assessment of the effects of annual forest cuttings, forest fires, agricultural burning and also from $^{13}C/^{12}C$ techniques indicates that the terrestrial biosphere may not only be a sink for CO_2 because of enhanced photosynthesis, but that it may also be a source for CO_2 because of deforestation and tilling of the soil. Thus, if the terrestrial biosphere acts as a source rather than a sink, and if the ocean-atmosphere models are sufficiently reliable to rule out additional CO_2 uptake by the oceans, one must search for other potential sinks that might be able to absorb the excess CO_2 from man's activities.

Budyko (1977) has shown that a temperature increase - caused, for example, by a CO_2 increase - reduces both the meridional temperature gradient and the amount of precipitation. Specifically, for the northern hemisphere, the average surface air temperature increase of 0.1° C over the past 10 yr has resulted in a concomitant decrease of 1.0% and 0.5% in the meridional temperature gradient for the winter and annual mean conditions, respectively. A decrease in the meridional temperature gradient leads to a reduction in the intensity of atmospheric circulation. A weakened atmospheric circulation transfers less water vapour from the oceans to land areas, thereby reducing the amount of precipitation. Thus, a plausible scenario of future events could have the following chain reaction: a CO_2 increase leading to an air temperature increase; a decrease in the meridional temperature gradient; a reduction of the intensity of atmospheric circulation; and a reduction in amounts of precipitation, thereby influencing agricultural productivity.

The author's estimate of man's impact on the global mean surface air temperature is based on the assumption that the "solar constant" and mean cloudiness remain relatively constant, that there will be no unusual increase in volcanic eruptions or Antarctic ice surges, and that the present energy growth, based on an energy mix dominated by fossil fuels, will continue. Except for changes in the surface albedo and the stratospheric ozone, all other activities of man should theoretically cause a global warming. On balance, it appears that the combination of

Continued ...

Bach, W. 1979. Continued

all effects might lead to a mean global warming of 0.8 to 1.2° C by 2000 A.D. and of 2 to 4° C by 2050 A.D.

The author suggested that the increasing CO_2 concentrations in the atmosphere are a major factor in the warming trend and indicated that the above average temperature changes will be three to five times larger in polar regions. According to the author's model, the expected future increase in atmospheric CO_2 concentrations will be accompanied by air temperature increases that are positively correlated with latitude, resulting in a general poleward shift of climatic zones suitable for agriculture. As a rule of thumb, a 1° C change in mean surface air temperature in summer at a given latitude corresponds to a 10-day change in the growing season.

As an interim measure to slow down the atmospheric CO_2 increase for a number of years until non-fossil fuels become available, there have been suggestions for establishment of a "carbon bank". This would involve the planting of fast-growing trees, such as the American Sycamore with yields of about 750 tons of carbon per km^2 per year, or the cultivation of aquatic plants, such as water hyacinths, with yields as high as 6,000 tons of carbon per km^2 per year. In effect, the cultivation of biomass in such energy plantations would not accumulate but rather recycle CO^2 in the atmosphere. As an unwanted side-effect, however, the newly grown forests would lower the albedo and absorb more heat, leading to more warming and thus reinforcing the CO_2 effect. It has been estimated that energy forests would have to extract the equivalent of about 20 kg of CO_2 per m^2 from the atmosphere just to compensate for the temperature increase caused by the expected albedo decrease of about 20%. Thus, it would appear that this type of CO_2 storage would not be very effective.

1. BAILEY, W.G.

2. 1981

3. The climate resources for agriculture in northwestern Canada.

4. Agriculture and Forestry Bulletin 4:11-17

5. a. Canada; Index maps NO-10, NO-11, NN-10, NN-11; Alberta; B.17, B.18a, B.19a

   b. Nil

   c. Climate/growth (direct relationships), Climate variation (regional, temperature, precipitation)

6. This article deals with the 9 million hectare Peace River region that lies within the closed forest zone of the boreal forest ecosystem and focusses on the physical elements of climate that are interlocked with the boreal forest ecosystem, as well as the climatic resources that are crucial to agricultural production.

Based on data from Hare and Ritchie (1972), the author points out that the boreal forest zones are not strictly latitudinal, but instead are displaced southward in eastern Canada. This reflects the role played by Hudson Bay in modifying eastern Canada's climate regimes. The agricultural lands in the Peace River region are often thought to be displaced northward and to be anomalous. In fact, a similar environment would be found all across Canada at a similar latitude if it were not for the cooling influence of Hudson Bay.

In the Peace River region, current agricultural lands are bounded by the 14° C isoline of mean growing season temperature; forests, for the most part, have mean growing season temperatures less than 14° C.

Agricultural lands in the Peace River region were developed from forested lands, and a comparison of forest and agricultural production is of interest. Regional yields in 1979 for rapeseed, barley, and wheat were 0.9, 2.3 and 2.3 t/ha. These values represent grain yields only and fail to account for production of other plant parts. The average regional yield of forage is approximately 5.6 t/ha, but the range is large (2.0 to 13.5 t/ha) as a consequence of agronomic practice and regional variations in climate. Hare and Ritchie (1972) presented ranges of standing biomass for the closed boreal forest zone of 150 to 400 t/ha with an annual production of 6 to 10 t/ha. There is thus a similarity of production values between the closed forest zone and agricultural lands. The higher maximum in herbage production reflects modern agronomic practice, particularly fertilizer application. The higher minimum production from the closed forest reflects the better adaptation of the forest ecosystem to environmental limitations. The low minimum production rates for forages reflect, for the most part, the inability of the crops to overcome limitations imposed during adverse growing season conditions.

1. **RAKUZIS Egolfs V. and Henry L. HANSEN**

2. 1965

3. **Balsam fir, Abies balsamea** (Linnaeus) Miller. A monographic review.

4. The University of Minnesota Press, Minneapolis. 445 p

5. a. Minnesota

   b. Balsam fir

   c. Climate/growth (direct relationships)

6. This text draws together the scattered information relating to balsam fir, an important tree constituent of boreal forests. The position of balsam fir among other species in Minnesota forests as indicated by the synecological coordinates for heat is shown in the table below, with higher values denoting warmer conditions. The heat coordinates presented here are average expressions of macroclimatic heat effects, as modified by microclimatic conditions, on trees growing in forest stands in competition with other species.

Tree species	Heat Coordinate	Tree species	Heat Coordinate
Larix laricina	1.0	**Acer saccharum**	3.5
Picea mariana	1.0	**Quercus rubra**	3.5
Thuja occidentalis	1.3	**Quercus macrocarpa**	3.8
ABIES BALSAMEA	1.4	**Tilia americana**	3.8
Picea glauca	1.5	**Ulmus americana**	3.9
Betula papyrifera	1.7	**Ostrya virginiana**	4.3
Pinus banksiana	1.9	**Fraxinus pennsylvanica**	4.4
Pinus strobus	2.0	**Quercus alba**	4.6
Populus balsamifera	2.1	**Carya cordiformis**	4.8
Populus tremuloides	2.1	**Acer negundo**	5.0
Pinus resinosa	2.1	**Populus deltoides**	5.0
Betula alleghaniensis	2.4	**Ulmus thomasii**	5.0
Acer rubrum	2.6	**Juniperus virginiana**	5.0
Fraxinus nigra	2.6	**Juglans nigra**	5.0
Quercus ellipsoidalis	3.0	**Celtis occidentalis**	5.0
Populus grandidentata	3.1	**Acer saccharinum**	5.0

Balsam fir withstands very low winter temperatures, but its reproduction may be hindered occasionally by early frosts and winter drying. It grows well in areas having low light intensities but abundant precipitation. Whether balsam fir is affected more or less adversely than other species by snow breakage, hail, and glaze damage is not known, but it is more subject to fire damage than a number of other species.

1. **BARANOV, A.F.**

2. 1980

3. Effect of climatic factors on the productivity of spruce stands.

4. Lesnoe Khozyaistvo (1980) 11:47-48

5. a. U.S.S.R.

   b. Norway spruce

   c. Climate/growth (direct relationships)

6. Investigations were made in pure Norway spruce stands in the Moscow region, to determine the effect of a set of climatic factors on their productivity. The mean height of the stands (site class II) in age class 80 to 100 yr was 25.2 m, mean diameter was 25.5 cm, basal area 36.8 m^2, and stemwood volume 449 m^3/ha. Multiple regressions were derived for 14 climatic factors. The best regression for stand productivity was one incorporating the diffuse solar radiation, the sum of air temperatures over 10° C, the number of clear days, and the mean annual precipitation.

1. **BARNEY, Richard J. and Keith VAN CLEVE**

2. 1973

3. Black spruce fuel weights and biomass in two interior Alaska stands.

4. Canadian Journal of Forest Research 3:304-311

5. a. Alaska

   b. Black spruce

   c. Biomass (tree, shrub/herb, moss/lichen)

6. The study area was located near Fairbanks, Alaska (64 45 N, 148 15 W). Annual precipitation in the vicinity of the study area is 28.7 cm; over 17.8 cm falls during May-September as rain. The annual means of maximum, average, and minimum temperatures are 0.24° C, -3.4° C, and -9.5° C respectively.

Mensurational data for the black spruce sites are given in Table 1.

Table 1. Mensurational data for upland and lowland black spruce sites near Fairbanks.

	Lowland site	Upland site
Moss depth, upper layer (cm)	7.1	3.6
Moss depth, lower layer (cm)	7.9	6.6
Average number of stems/ha	27,347	14,826
Average stem diameter (cm)	2.7	3.5
Average basal area (m^2/ha)	18.8	22.0
Average age (years)	51	55
Average height (m)	2.87	3.14

The authors compared biomass measurements with those in other regions of North America. In northern Quebec (Weetman and Harland 1964), the above-ground biomass in a 65 year black spruce stand of 91.7 t/ha was 3.9 and 5.8 fold greater than black spruce biomass in the lowland and upland stands, respectively, of this study (Table 2). Although stocking in the Quebec stand was less than half that of the Alaska stand, 7,114 stems/ha compared to an average for both Alaska stands of 21,079 stems/ha, basal area in the Quebec stand was approximately 2 fold greater, 41.7 m^2/ha compared with an average for both Alaska stands of 20.4 m^2/ha.

Biomass measurements in a 350 year white spruce alpine fir stand in Alberta are compared to the Alaskan biomass data in Table 2.

Continued ...

Table 2. Comparison of fuel weight data for an Alberta spruce-fir stand and Alaskan black spruce.

	Spruce-fir (Kiil 1969)	Alaskan black spruce: Upland	Alaskan black spruce: Lowland
Tree components, O.D. (t/ha)			
stems 0 - 1.3 cm	21.1	8.4	11.1
stems 1.3 - 5.1 cm	10.1	6.7	8.1
stems 5.1 cm +	70.6	1.0	4.9
Minor vegetation, O.D. (t/ha)	0.4	1.5	1.7
Moss, upper layer, O.D. (t/ha)	10.8	38.4	16.2
Fermentation and humus layer, O.D. (t/ha)	139.0	84.1	85.8
Total, O.D. (t/ha)	252.0	140.1	127.8
Dead woody material (t/ha)		4.8	4.1
Moss depth (cm)	4.6	7.1	3.6
Fermentation and humus layer depth (cm)	10.9	7.9	6.6

In a 43 year balsam fir-white spruce-paper birch stand in New Brunswick, total above-ground biomass was recorded as 196.5 t/ha (Baskerville 1966). Lesser vegetation in the New Brunswick stand weighed 0.2 t/ha compared to 1.5 and 1.8 t/ha in the Alaska black spruce stands. The forest floor weight of 0.24 t/ha reported from New Brunswick is considerably less than the values obtained in the Alaska stands where forest floor weights were 120.1 and 100.1 t/ha for lowland and upland black spruce stands, respectively.

Total above-ground tree weight for black spruce found on the Yukon Flats of Alaska ranged from 0.1 to 42.5 t/ha (Johnson and Vogel 1966). The black spruce upland site of the two sites described near Fairbanks is approximately midway in this range. The total above-ground production, excluding moss and humus, for the Yukon Flats stands ranged from about 1?.9 to 43.6 t/ha compared to about 22.0 and 27.5 t/ha for the same parameters in the Fairbanks lowland and upland black spruce sites, respectively.

1. **BARNEY, Richard J., Keith VAN CLEVE and Robert SCHLENTNER**

2. 1978

3. Biomass distribution and crown characteristics in two Alaskan *Picea mariana* ecosystems.

4. Canadian Journal of Forest Research 8:36-41

5. a. Alaska

   b. Black spruce

   c. Biomass (tree)

6. The objective of this study was to develop allometric relations of tree phytomass distribution from two distinct black spruce stands, one from an upland site and one from a lowland site, in the Bonanza Creek Experimental Forest about 32 km west of Fairbanks (64 45 N, 148 15 W).

The authors developed biomass regressions that allow prediction of component weights from a knowledge of stem basal diameters. As an example, the regressions allow one to estimate that for a range of diameter classes from 0.32 to 7.94 cm foliage comprises from 37% to 17% of the total tree mass for the lowland stand and 50% to 17% of the total mass in the upland stand.

Biomass regression equation coefficients for the equation

$$\log_e Y = a \times b \log_e X,$$

where Y = mass in grams (dry), and X = basal diameter in centimetres, are summarized in the tables below. The intercept, a, was corrected for logarithmic bias according to the procedure of Baskerville (1972).

LOWLAND BLACK SPRUCE

Components, mass, g (y)	Intercept (a)	Slope (b)	R^2
Foliage	2.70	2.15	0.82
Cones, live and dead	2.20	1.70	0.47
Dead branch, total	1.41	2.45	0.89
Dead branch bark	0.99	2.43	0.88
Dead branchwood	0.22	2.59	0.83
Live branch, total	1.51	2.53	0.84
Live branch bark	1.01	2.56	0.89
Live branchwood	0.60	2.48	0.74
Bole, total	2.34	2.90	0.84
Bole, bark	1.45	2.82	0.84
Bole, wood	1.74	3.03	0.75
Tree, total	3.50	2.59	0.92

Continued ...

UPLAND BLACK SPRUCE

Components, mass, g (y)	Intercept (a)	Slope (b)	R^2
Foliage	2.74	2.09	0.82
Cones, live and dead	1.45	1.77	0.51
Dead branch, total	0.50	2.78	0.69
Dead branch bark	0.34	2.65	0.24
Dead branchwood	-1.18	3.11	0.83
Live branch, total	1.55	2.48	0.97
Live branch bark	1.24	2.38	0.99
Live branchwood	0.29	2.65	0.89
Bole, total	2.63	2.74	0.92
Bole, bark	1.80	2.51	0.94
Bole, wood	2.09	2.85	0.90
Tree, total	3.63	2.54	0.91

The authors obtained above-ground tree dry weights of 16,136 kg/ha from direct field sampling in the lowland site and 24,056 kg/ha in the upland site.

winters in the late 19th century; b) increasing vigour of the circulation with considerable warmth culminating in the 1920's and 1930's; and c) a sharp decrease in circulation intensity, and cooling in many areas, starting about 1950.

The temperature reconstruction for Iceland underlines the abruptness of the 20th century warming and cooling and its apparent uniqueness in the context of the last 1,000 yr. Clearly, the standard climate 'normals' for 1901-1930 and 1931-1960 are not representative of the historical era. These fluctuations were most pronounced in higher latitudes in the Atlantic-European sector, but even in the British Isles the changes were sufficient to be of significance in terms of growing season characteristics and winter snowfall. The same conclusions are reached for the eastern United States. Lamb's studies suggest that for the Atlantic-European sector there is an approximately 200-yr fluctuation in the strength of the westerlies, with peaks in the early 1300's, 1500's, 1700's and 1900's.

A key question is whether variations in circulation intensity in one sector represent an overall change in the circumpolar vortex or whether they indicate only a shift in tropospheric wave pattern. There is now clear evidence that since 1900 most of the fluctuations of pressure and temperature in the northern hemisphere have been related to short-term displacements of the wave pattern or changes in wave amplitude.

The problem of linking changes in climatic conditions with circulation changes has received only limited attention. Some investigators have argued that changes in climate result from changes in the frequency of circulation types. It has also been shown that zonal patterns decreased after 1950, whereas meridional ones increased by comparison with the period from 1900 to 1950. This matches the observed cooling trend in various parts of the northern hemisphere. Cooling is most pronounced in regions affected by northerly flow components such as eastern North America.

The principal area of uncertainty concerns the basic characteristics of atmospheric circulation fluctuations and especially their regional manifestations. The complex relationships between wave amplitude and spacing, circulation intensity and the nature of latitudinal displacements of the global wind systems are inadequately known.

1. BARRY, R.G.

2. 1981

3. The nature and origin of climatic fluctuations in northeastern North America.

4. Geographie Physique et Quaternaire XXXV:41-47

5. a. Northern hemisphere

   b. Nil

   c. Climate (air masses), Climatic variation (regional)

6. The atmospheric circulation over eastern Canada is dominated by a mean tropospheric trough, located about 70 00 to 75 00 W in both winter and summer. This feature of the hemispheric long-wave structure is primarily caused by differential land-sea heating effects on the lower troposphere reinforced, mainly in winter, by large-scale orographic influences on the flow at upper levels downstream of the mountain ranges of western North America. Despite the seasonal reversal of the land-sea thermal gradient, a weaker upper trough and a surface low are present over the area in summer. The mean trough is important climatically since it reflects the general steering of surface cyclones, roughly parallel to the mean 500 mb contours. Also, throughout the year, although less frequently in summer, lower level cyclonic vorticity is enhanced on the eastern limb of an upper trough by high level divergence, and hence cyclones tend to regenerate or intensify over the Labrador Sea. From here, a frequent track enters Davis Strait-Baffin Bay where many systems slowly decay. A mean frontal zone crosses the central part of the Labrador-Ungava Peninsula in summer; poleward of this front, arctic air predominates and this boundary, in summer, seems to be closely related to the present forest-tundra ecotone in both North America and Eurasia (Bryson 1966, Krebs and Barry 1970).

The mean trough varies in location and amplitude in relation to changes in external thermodynamic forces. It has been shown that displacements of the mean 700 mb trough in summer occur in association with changes in the strength of the hemispheric westerlies and concomitant adjustments in the wavelength of the mean wave structure. The trough displacements are attributed to circulation readjustments induced by tropospheric cooling in high latitudes which accentuates the north-south thermal gradient and thereby strengthens the westerlies. In turn, this increases the wavelength downstream of the more "anchored" Alaska-Yukon ridge.

The summer cooling, associated with an eastward-displaced trough in the case of Baffin Island, is not apparent further south. In the subarctic, cool summer months are more apparent in Labrador-Ungava and Keewatin when the trough is deeper than normal over Hudson Bay. Such months are also wetter than average over Labrador-Ungava and drier west of the Bay. When the trough is displaced eastward, Keewatin and the Hudson Bay area tend to be drier than average with heavy precipitation over Labrador.

Continued ...

1. BARRY, R.G.

2. 1967

3. Seasonal location of the arctic front over North America.

4. Geographical Bulletin 9:79-95

5. a. Canada; Index maps (all in boreal zone); all boreal forest sections in Canada

   b. Nil

   c. Climate (air masses), Climatic variation (regional)

6. On a routine synoptic basis, the Meteorological Branch prepares frontal contour charts that show the locations of the polar front, the maritime arctic front, and the continental arctic front at the 850 mb, 700 mb and 500 mb pressure levels. The ecological significance of seasonal locations of the arctic front (Bryson 1966) led the author to re-examine the occurrence of this front using frontal contour charts as a source of information.

On the basis of his analyses, the author concluded that the January location of the arctic frontal zone shown by Bryson (1966) appears to represent the continental arctic front, although the Newfoundland sector requires further checking. The July or summer position shown by Figure 33 of Bryson (1966) is equivalent to the continental arctic front over the Northwest Territories and the maritime arctic front from about 115° to 90° W. East of there it is apparently a median line relating to a broad baroclinic zone which is represented as a dual frontal zone by Canadian meteorologists.

Studies by the University of Wisconsin Meteorology Department have documented apparent correlations of the southern limit of arctic air dominance in summer and winter with the respective northern and southern margins of the boreal forest zone in central Canada (Bryson 1966). The findings of this study lend support to Bryson's results in northwest Canada where the forest-tundra boundary is extremely sharp, but suggest that the correlation may not be applicable in Labrador-Ungava. The forest boundary in Labrador-Ungava is undoubtedly greatly affected by topographic and edaphic factors.

The author indicated that although the median July position of the arctic front in the northwest is in close agreement with Bryson's findings, the relationship between the arctic front and boreal forest/tundra boundary warrants further investigation before it can be extended to eastern Canada.

1. BARRY, R.G.

2. 1978

3. Climatic fluctuations during the periods of historical and instrumental record.

4. IN: A.B. Pittock, L.A. Frakes, D. Jenssen, J.A. Peterson, J.W. Zillman, Editors, Climatic change and variability, a southern perspective. Cambridge University Press, New York. p. 150-166

5. a. Northern hemisphere

   b. Nil

   c. Climatic change (hypotheses, dendrochronology, proxy data), Climatic variation (temporal)

6. Recent concern about world food supplies has focussed on climatic variability at time scales between 1 and 100 yr. Climatic records during the 20th century have graphically demonstrated the fallacy of the concept of a climatic 'normal' state and the need to consider climate as an environmental variable. However, a realistic perspective of these recent fluctuations must span at least the last half millennium if one wishes to characterize the rates and magnitudes of the changes and their possible causes. In this context, the author outlined the available data base, present views of the nature of the fluctuations and their relation to the general circulation. The sources of evidence for short-term climatic variability are of three types: instrumental records, historical evidence of climate-related phenomena and proxy records of environmental variables sensitive to climate.

In his review of dendroclimatology as a form of proxy data, the author emphasized that dendroclimatology affords the unique possibility of reconstructing seasonal conditions for individual years over at least several centuries. For individual ring-width chronologies, the record extends beyond 8,000 yr BP.

The author graphed climatic changes in the northern hemisphere over the last 1,000 yr, using reconstructed temperature trends for China and Japan, compared with England and Iceland. Inspection of the graphs indicates that while the changes in China and Japan were broadly in phase with one another, the Little Ice Age appears to have begun in the 10th century in east Asia and temperatures there reached a minimum in the 12th century. The cooling apparently spread westward, reaching European Russia in the mid-14th century and central Europe in the mid-15th century. Such displacements and longitudinal relationships are suggestive of adjustments in the tropospheric wave structure.

The last 100 to 150 yr, which is well covered by instrumental records, includes some remarkable climatic fluctuations. In the northern hemisphere these are: a) a period of weak zonal circulation and cold

Continued ...

Barry, R.G. 1981. Continued

For winter months, snowy "mild" conditions affect both Keewatin and Labrador-Ungava when the 700 mb trough is weaker than normal and displaced westward, with anomalous southeasterly flow components advecting heat and moisture from the western north Atlantic. It should also be noted that recent work indicates that, while snowy months tend to have positive temperature anomalies, there is no significant correlation between temperatures and snowfall amount.

The work described by the author supports earlier analyses which show that climatic anomalies a few decades in length are linked closely to anomalies in the modes of atmospheric circulation. The tendency for circulation modes is a well documented feature of at least the winter season in the northern hemisphere. A north Atlantic pressure oscillation and an analogous north Pacific oscillation have been described. Each oscillation represents a major independent element of hemispheric circulation and both contribute to regional climatic anomalies, including temperature and sea-ice conditions. The north Atlantic oscillation in particular displays connections over a large part of the hemisphere.

A dominant east-west mode of variation in large-scale annual anomalies over the United States for three subperiods within the meteorological records (for the period 1895 to 1977) has also been described. A circulation connection is generally less obvious in summer than in winter, due to weaker temperature gradients and lesser wave amplitude. However, since trends in the relative frequency of cyclonic activity over areas occupied by stable air masses may be sufficient to account for the observed temperature trends, it is unlikely that such intervals of cyclonic activity would continue in the same sense for more than one hundred years. If this is so, then these short term events may be of limited use as an analog to past climatic changes of longer duration.

1. BASKERVILLE, G.L.

2. 1965

3. Dry-matter production in immature balsam fir stands.

4. Forest Science - Monograph 9, 42 p.

5. a. Canada; Index map NL-19; New Brunswick; B.2

   b. White birch, balsam fir, black spruce, white spruce

   c. Biomass (tree)

6. This monograph presents the results of an above-ground forest production study in natural immature fir-spruce-birch stands of varying density in northwestern New Brunswick (47 51 N, 68 20 W). Sampling took place in stands with the following numbers of tree stems per hectare: 1730, 2470, 3700, 4940, 7410 and 12,350.

The results showed that the denser stands, with their larger numbers of smaller crowns, were the highest producers of dry matter. Since the critical factor in explaining a theoretical drop in production at high density was thought to be the amount of respiring surface area, this factor was carefully analyzed. Both bole surface area and branch surface were found to increase with increased density as expected. Either this increase is not enough to produce an inefficient balance of nonphotosynthetic area to photosynthetic area or else surface area is not a good measure of respiring tissue.

For the stands sampled, the author could not confirm the assumption that the amount of foliage is constant for all densities. There was a weak but significant tendency towards increasing amounts of foliage with increasing numbers of trees per unit area of land.

The principal findings listed by the author were as follows:

1. The relationships of such factors as stem height, form and volume, stem weight, crown weight, weight of branches, and the increment of these factors, to stem diameter at breast height are independent of stand density.

2. Average specific gravity of stem wood decreases exponentially with increasing stem diameter at breast height but, for a given diameter, is independent of stand density.

3. Total dry weight of foliage per unit area of land and current annual increment of cubic volume and of dry weight all increase linearly with increasing stand density.

Continued ...

Baskerville, G.L. 1965. Continued

4. Small crowns produce more tissue per unit weight of foliage than large crowns. This is thought to result from a combination of the low light saturation point of photosynthesis in balsam fir, the high proportion of shade needles in small crowns, and the favourable distribution of dry matter among tree components in small trees.

5. Spruce crowns are slightly more efficient than fir in production per unit weight of foliage. White birch crowns produce roughly three times as much dry matter per unit weight of foliage as either spruce or fir. However, because of differences in crown size, the weight of organic matter produced per unit area of basal area is greatest for balsam fir followed by spruce and birch.

1. BASKERVILLE, G.L.

2. 1966

3. Dry-matter production in immature balsam fir stands: roots, lesser vegetation, and total stand.

4. Forest Science 12:49-53

5. a. Canada; Index map NL-19; New Brunswick; B.2

   b. White birch, balsam fir, black spruce, white spruce

   c. Biomass (tree, shrub/herb)

6. This paper supplements the above-ground tree production data presented by Baskerville (1965) for balsam fir, white spruce and white birch stands of six different stand densities in northwestern New Brunswick (47 51 N, 68 20 W).

Dry weight of total tree standing crop, including roots, and dry weight of understory vegetation was estimated for each of six density classes (number of tree stems per hectare) as summarized in the table below.

	Density (stems/ha)					
	1730	2470	3700	4940	7410	12300
	oven-dry wt, t/ha					
Tree layer						
balsam fir	123.28	126.50	144.66	163.30	170.97	187.71
white spruce	12.39	1.21	0.92	1.03	6.05	6.32
white birch	1.21	4.66	3.27	2.53	5.51	5.74
all tree species	136.88	132.37	148.85	166.86	182.53	199.77
Shrub layer	*	*	*	*	*	*
Herb/moss layer	0.63	0.58	0.11	0.09	0.11	0.23

* under .01 t/ha

The total dry weight of fir root systems increased from 26.7 t/ha at 1,730 stems/ha to 43.7 t/ha at 12,300 stems/ha. The proportions of spruce and birch in the stands were variable across the range of density, with the result that there was no definable trend in the root weights of these species. Roots accounted for 21.7% of the fir stand at 1,730 stems/ha and 23.3% at 12,300 stems/ha. This trend results from the fact that roots represented a slightly larger proportion of small fir trees than they did of large trees. The corresponding percentages for spruce did not indicate a trend because of the small number of trees involved and the consequent increased influence of tree size. With changing density the proportion of the birch stand comprised in roots appears to remain constant at about 23%. However, because of the high proportion of the total stand in fir the percentage of the total stand in roots tended to increase with increasing density.

Continued ...

Baskerville, G.L. 1966. Continued

In summary, the oven-dry weight of total standing crop in the sampled 43-yr-old fir-spruce-birch stands increased with increasing stand density. The total weights of tree roots increased with increasing stand density as did the weight of the above-ground tree stand. Roots formed a slightly greater proportion of the total stand in the denser stands. The dry weight of vegetation on the forest floor (herbs and mosses) tended to decrease with increasing density but the total weight involved was insignificant in comparison to the total tree stand.

1. BAUMGARTNER, A. and M. KIRCHNER

2. 1980

3. Impacts due to deforestation.

4. IN: W. Bach, J. Pankrath and J. Williams, Editors, Interactions of Energy and Climate, Proceedings of an International Workshop held in Münster, Germany, March 3-6, 1980, D. Reidel Publishing Co., Boston. p. 305-316

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels)

6. The question of how forestry operations influence the carbon and carbon dioxide transfer between earth and atmosphere has gained considerable interest. The authors point out that it is necessary to distinguish between managed operations in forests and the disorganized destruction of stands. The carbon dioxide balance for a managed spruce forest at the German IBP-Station at München-Ebersberger Forst is given below:

Crown, inflow (F)	46 t CO_2/ha/yr
Crown, outflow (F_r)	19 t CO_2/ha/yr
Crown, net inflow	26 t CO_2/ha/yr
Soil, outflow (F_s)	18 t CO_2/ha/yr
Net assimilation (1972)	8 t CO_2/ha/yr

At the time of this study, the forest was about to be harvested for timber. It had recently stored about 300 t carbon/ha and was fixing 8 t of carbon dioxide/ha/yr. Concerning the CO_2 exchange, the managed forest was in an unbalanced state, as the successions to equilibrium between assimilation and respiration were interrupted. Therefore, this forest type was classified as a sink of CO_2. This suggests a global total of the CO_2 sink of 1.5×10^9 t/yr. This is only about 2% of the annual fixation rate of CO_2 by assimilation, which is about 80 to 100×10^9 t of carbon dioxide for the entire globe. The authors' summary of above-ground production in various climatic zones is listed below:

	Area 10^6 ha	%	Annual production, above-ground $\times 10^9$ t, dry	%
Tropical	2,150	53	29.4	75
Temperate, warm	360	9	5.0	13
Temperate, cool	260	6	2.8	7
Boreal	1,300	32	1.8	5

Continued ...

Baumgartner, A. and H. Kirchner. 1980. Continued

The authors stress that when evaluating global carbon dioxide balances one cannot neglect the exchanges by forests. The integrated effect of forestry operations may be a source of CO_2 up to 15×10^9 t of carbon dioxide. This is about the magnitude of the carbon dioxide release by burning of fossil fuels (oil, coal, or gas).

By simulation one is able to calculate the effects of total deforestation of the globe. Based on world maps of albedo, roughness parameters, and deviation angles betweeen geostrophic winds and isobars, the effects of global deforestation have been estimated. If there were global deforestation, the global average surface albedo would shift from 16.7% to 17.4%, which means that the globe would be brighter and would initially absorb less solar radiation. The roughness of the earth would decrease significantly in the case of total deforestation and the authors' model suggests that roughness should decrease mainly in the northern hemisphere. The global decrease of the deviation angle between geostrophic wind and the isobars is roughly 1 degree. The authors predict that a remarkable rise of atmospheric CO_2 content would follow global deforestation, caused by the reduction of assimilation and by the release of carbon from biomass and within the soil. The atmospheric CO_2 supply could be depleted totally by forest production within 26 yr if there was no CO_2 return from plant metabolism.

1. BAZILEVICH, N.I., A.V. DROZDOV and L.E. RODIN

2. 1971

3. World forest productivity, its basic regularities and relationship with climatic factors.

4. IN: P. Duvigneaud, Editor, Productivity of forest ecosystems, Proceedings of the Brussels symposium organized by UNESCO and the International Biological Programme (27-31 October 1969), UNESCO, Paris. p 345-353

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb), Climate/growth (direct relationships)

6. Relationships between the productivity of plant communities and the hydrothermal regime of an area have been proposed in research by Budyko and Grigorjev, and the relationships are examined in this paper for various forested ecosystems. Budyko and Grigorjev estimated the influence of heat and moisture on plant productivity by means of annual values of the radiation balance (R, kcal/cm^2/year) and the radiation index of aridity denoted by R/Lr, where r is the quantity of heat required to evaporate the total annual precipitation (r = precipitation, L = the latent heat of the phase changes). Grigorjev and Budyko advanced the following hypotheses:

   1. The productivity of plant communities reaches its maximum at an optimal value of R/Lr approaching 1 and decreases at R = constant, when R/Lr ratios deviate from the optimal value.

   2. At the optimal value of the R/Lr ratio, the greater the absolute values of R and Lr the higher is the plant productivity.

The authors computed data on aggregate (above-ground and below ground) annual increment of biomass, expressed as dry weight of organic matter per unit area of land (t/ha/yr) and this productivity parameter to radiation balance and to radiation aridity index, as shown in the table on the following page.

The authors summarize the joint effects of heat and moisture as follows: if the values of the radiation balance do not exceed 40 kcal/cm^2/year, productivity rises quickly following an increase in heat; however, under high values of R (greater than 40 kcal/cm^2/year) the productivity increment is predominantly influenced by the availability of moisture, this being especially noticeable when the aridity index drops below 1.

Continued ...

Bazilevich, N.I., A.V. Drozdov and L.E. Rodin. 1971. Continued

Types of forest (locality)	Aggregate annual increment (t/ha)	Radiation balance (kcal/cm^2/yr) (R)	Radiation aridity index (R/Lr)
Green-mossy spruce forest (N. taiga, U.S.S.R.)	5.6	23.5	0.74
Bilberry spruce forest (N. taiga, U.S.S.R.)	6.5	25.0	0.82
Green-mossy spruce forest (N. taiga, U.S.S.R.)	6.0	25.0	0.83
Bilberry spruce forest, grass-green-mossy spruce forest (middle taiga, U.S.S.R.)	6.0	29.5	0.82
Mixed spruce forest (middle taiga, U.S.S.R.)	9.0	33.0	0.75
Sedge-goutweed lime forest (U.S.S.R.)	8.4	34.0	0.90
Oak forest (U.S.S.R.)	7.2	36.5	1.10
Sedge-goutweed oak forest (U.S.S.R.)	8.1	36.0	1.03
Beech forest (W. Europe)	13.0	40.0	0.70
Dry savanna (India)	7.3	73.0	2.38
Savanna (Ghana)	15.0	67.0	0.93
Subtropical camphortree forest (Japan)	20.5	68.0	0.69
Rain forest (Thailand)	32.3	70.0	0.47
Equatorial forest (secondary) (Congo)	33.0	70.0	0.58

The authors conclude that with a change of the aridity index towards overmoistening (up to a value of 0.5) and values of R exceeding 40 kcal/cm^2/year, a significant increase can be observed in the productivity of forest ecosystems. This means that an aridity index equal or close to 1 is not an optimal one for maximum productivity in all thermal zones.

1. BAZILEVICH, N.I. and L.E. RODIN

2. 1971

3. Geographical regularities in productivity and the circulation of chemical elements in the earth's main vegetation types.

4. Soviet Geography 12:24-53

5. a. U.S.S.R.

   b. Nil

   c. Biomass (tree, shrub/herb)

6. In this review article, the geographical distribution of potential productivity and of biological circulation in the principal vegetation types is analyzed in terms of several parameters: 1) phytomass reserve of plant communities; 2) annual growth of a community; 3) chemical make-up of the nutrient elements drawn into the biological circulation; 4) ash content in organic matter of a year's growth ; 5) carrying capacity of biological circulation, based on the amount of chemical elements drawn into the production of a year's growth; and 6) rate of decomposition of plant remains in the litter and the rate of release of chemical elements. These parameters are mapped and their geographical regularities are analyzed. The magnitude of a year's growth, as well as the carrying capacity and intensity of biological circulation, are found to increase from tundra to coniferous forest and on to broadleaf forest and steppe, reaching a high level in the humid subtropics and tropics. In desert, both annual growth and carrying capacity are at a minimum, but the intensity of biological circulation is high.

The authors stress that the earth's living matter consists predominantly (almost 99%) of the organic mass of plant organisms. Very little is represented by animal organisms. The geochemical role of living matter can therefore be viewed essentially as the work of green plants.

The authors' analyses revealed that although phytomass accumulation reaches a maximum in forest, the maximum annual growth is associated not with forest, but with such herbaceous-woody and herbaceous communities as the savanna, pampas, steppe and herbaceous-woody vegetation types that border forest types. Their analyses suggest that an equivalent quantitative effect is being achieved by what would appear to be totally different and widely separated types of plant communities. Similar accumulations of phytomass are associated, for example, with tundra and steppe; identical annual growth is evident in broadleaf forest, pampas and in northern taiga and dry steppe. In other words, certain combinations of external factors - light, heat, moisture, mineral nourishment - produce complex biogeocenotic interactions that yield more or less similar results in the amount of organic matter created. Future research should be designed to identify all these interactions and the determinant factors to establish correlations among them.

1. BAZILEVICH, N.I., L. Ye. RODIN and N.N. ROZOV

2. 1971

3. Geographical aspects of biological productivity.

4. Soviet Geography 12:293-317

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb), Climate/growth (direct relationships)

6. The authors have compiled world maps of vegetation and soils, computed the areas occupied by different soil and plant formations, and determined the parameters of biological production for many of them. It is known that the living matter on earth is made up almost entirely of autotrophic, photosynthesizing plant organisms, which account for more than 99% of the total with animal biomass making up only 1%. For this reason, the authors focus on primary production created by green plants. The parameters for plant mass and annual plant production used in this paper include both the above-ground and the below-ground parts of plants in weight units of absolutely dry matter. Both plant mass and annual production can be computed either on a per unit area basis or as aggregate values on the basis of the areas occupied by different vegetation units.

In a sequence from the polar region through the boreal, subboreal and subtropical to the tropical region, the difference between maximum and minimum values of plant mass in the zonal vegetation types tends to increase because the maximum values increase and the minimum values decline.

The total plant mass of the earth's land area adds up to 2.4×10^{12} t. Of this total, the tropical belt accounts for 1.35×10^{12} t, or more than 56% of the total terrestrial plant mass, excluding streams, lakes and glaciers. Second to the tropical zone is the boreal zone, with 18% of the total plant mass as detailed on the following page.

The geographic regularities of distribution of both the annual plant growth and plant mass suggest a close relationship to climate. This relationship has been analyzed in the literature by Budyko and co-workers, and also by the authors of this paper. The latter analyzed plant production and specific habitat conditions of plant communities in terms of the influx of heat (R in kcal/cm^2/yr) and moisture (using the dryness index R/Lr, where r is precipitation and L the latent heat of phase transformations). The authors found that an increase in heat resources results in greater plant production especially for values of R less than 35 to 40 kcal/cm^2/yr (in regions north of the middle taiga subzone). For values of R greater than 35 to 40 kcal/cm^2/yr, moisture is the more significant factor. The annual production was found to reach a maximum in regions where R is less than 35 to 40 kcal cm^2 yr and the dryness index is greater than one (in the northern taiga, where it is 1.2, and in the

Continued ...

tundra 1.5) and in regions where R is greater than 35 to 40 kcal/cm^2/yr and the dryness index is less than one (in the subtropical belt 0.7, and in the tropical belt 0.5). These findings represent a correction of previous work by other authors and suggest that when heat is sufficiently great, excess moisture will yield greater production, but when heat is inadequate, excess moisture will result in less production. A good illustration is provided by the productivity of floodplain formations of the subtropical and tropical belts, where annual growth may be 90 t/ha/yr or more.

The authors stressed that a simple heat-moisture ratio does not explain all the regularities in the distribution of plant productivity. Other factors are the duration of the growing season and "productive moisture", which is precipitation minus surface runoff. Other researchers have proposed a hydrothermal potential of productivity (K_p) based on the formula: $K_p = W \times T_v/36 \times R$ (where W is the mean annual productive moisture supply of an area in millimetres, i.e., precipitation minus runoff; T_v is the length of the growing season in 10-day periods; R is the mean annual radiation balance in kcal/cm^2). A clearly defined correlation was found to exist between K_p and plant production.

The authors' summary of plant mass and annual production for subdivisions of the boreal zone is as follows:

BOREAL ZONE, HUMID & SEMIHUMID REGIONS	Plant Mass t/ha	Plant Mass 10^9t	Production t/ha/yr
Maritime formations on volcanic ash	100	1,350	10.0
Forest-tundra on grey podzolic soils	125	11,000	5.0
Same, on gley-permafrost taiga soils	100	12,190	4.0
Middle taiga forest on podzolic soils	260	92,846	7.0
Same, on permafrost taiga soils	200	49,260	6.0
Southern taiga on turf-podzolic soils	300	45,460	7.5
Same, on yellowish-podzolic soils	350	13,755	10.0
Same, on turf-calcareous and turf-gley soils	301	10,535	10.0
Same, on taiga bog soils with bogs	80	6,824	4.0
Small-leaf forest on gray solodized soils	200	4,540	8.0
Broadleaf forest on gray forest soils	370	26,307	8.0
Bogs	35	4,892	3.5
Floodplain formations	60	3,558	6.0
Forests on mountain podzolic soils	170	45,832	6.0
Same, on mountain permafrost soils	160	48,640	5.0
Mountain meadows on gray mountain forest soils	300	7,360	7.5
Mountain meadows on mountain meadow soils	35	5,513	12.0
Total	189	439,061	5.5

1. BEATTIE, Kathleen G., Wayne K. BOND and Edward W. MANNING

2. 1981

3. The agricultural use of marginal lands: A review and bibliography.

4. Environment Canada, Lands Directorate, Ottawa. Working Paper No. 13. 90 p

5. a. Canada; Index maps (all in boreal region); all boreal forest sections in Canada

   b. Nil

   c. Climate/growth (direct relationships), Growing season (length, degree-day totals, frosts)

6. Over time, the agricultural frontier advances in some regions and retreats in others. This paper reviews the Canadian experience along the agricultural margins some of which join the boreal region. The physical, economic and social factors that create retreating margins and advancing frontiers are reviewed, and sections of the review that deal with climatic factors at the boreal fringe of agriculture in Canada are summarized below.

The agricultural frontier is advancing most notably in the Peace River country of Alberta and British Columbia as well as in northern Saskatchewan and Manitoba. Minor advances were also reported in parts of Newfoundland. Retreat is occurring in the Maritime provinces, especially New Brunswick, and throughout Quebec, particularly in the Gaspé, the Beauce and the north shore of the St. Lawrence River. The margins are also retreating in the Muskoka-Haliburton area and throughout most of the clay belt in northern Ontario and western Quebec.

The authors discuss several climatic parameters: temperature regimes, frost-free period, and bright sunshine. The accepted minimum requirement for any agricultural production is 1,000 degree-days above 42° F (5° C). Marginal areas of agriculture generally have indices of degree-days ranging from 2,000 to 2,500, with some exceptions both below and above, while prime agricultural areas generally receive between 3,000 and 4,000 or more degree-days above 42° F (5° C). For example, index readings of 1,500 to 2,000 are found in the marginal agricultural areas of Newfoundland, northern New Brunswick and the Gaspé, as well as in portions of the central Yukon and Mackenzie Basin. Marginal agricultural lands registering between 2,000 and 2,500 degree-days above 42° F (5° C) include those found in central and western Quebec along the southern margins of the Shield, the clay belt farming region of northern Ontario, as well as those marginal lands in the Peace River district of northern Alberta and British Columbia. Areas of marginal agriculture with fairly high degree-day levels of 2,500 to 3,000 are found in the Muskoka-Haliburton and Renfrew areas of central and eastern Ontario.

Continued ...

The growing season is not identical to the frost-free period. Typically, the growing season begins three to five weeks earlier and ends three to six weeks later than the average frost-free period. A minimum of 80 frost-free days is required for the successful production of hardy crops. However, frost limitations to agricultural production are not uniformly restrictive over a wide area. Factors such as local topography, land use and close proximity to water bodies can cause marked contrast in the length of the frost-free season over short distances.

The duration of direct sunlight or photoperiod is another important factor related to the time/energy requirements for crop production, especially in northern marginal areas where the daily amount of sunlight controls, to a certain extent, the rate of crop maturation. At northern latitudes, the extra hours of daylight compensate for low degree-day averages by allowing certain hardy crops capable of continuous growth through the long summer day to mature early enough to escape killing frosts.

It has been estimated that a 1° C average cooling would reduce Canada's potential cropland for wheat by one-third, including virtually all of the advancing frontier areas in western Canada and much of the retreating margins in eastern Canada.

1. BELLA, I.E. and J.P. De FRANCESCHI

2. 1980

3. Biomass productivity of young aspen stands in western Canada.

4. Environment Canada, Canadian Forestry Service, Edmonton. Information Report NOR-X-219. 23 p

5. a. Canada; Index maps NN-11, NN-12, NN-13; Alberta, Saskatchewan; 8.18a

   b. Aspen, balsam poplar

   c. Biomass (tree)

6. The authors developed equations and tables for above-ground tree component dry weights for fully stocked aspen stands up to 40 yr old growing on different sites in the mixedwood forests of Alberta and Saskatchewan. Component and total weight regressions developed for individual aspen and balsam poplar trees are presented in the table below. The combined variable term, $\ln(D^2H)$, in which D = diameter at breast height outside bark (cm) and H = total tree height (cm), generally explained over 98% of the variation in component or total tree weight for either species. The exception was the branches and leaves component, for which 82.3% of the variation was explained for aspen and 86.6% for balsam poplar.

Component dry weights* (g)	Regression statistics** a***	b	r^2
Aspen (n = 279)			
Y_1	-1.70703	0.979867	0.992
Y_2	-1.16921	0.955453	0.991
Y_3	-0.89667	0.942525	0.988
Y_4	-1.77476	0.848092	0.823
Y_5	-0.80319	0.936736	0.987
Balsam poplar (n = 61)			
Y_1	-1.33769	0.936371	0.984
Y_2	-1.05307	0.931756	0.988
Y_3	-0.94500	0.927708	0.990
Y_4	-1.53009	0.777939	0.866
Y_5	-0.74651	0.913854	0.989

* Y_1 = ln(stem wood to 2-cm top); Y_2 = ln(stem wood + bark to 2-cm top); Y_3 = ln(stem wood + bark + branches); Y_4 = ln(branches + leaves), leaves include twigs; Y_5 = ln(total tree above ground)

** D and H in cm for the tree component weight regression of $\ln W = a + b \ln(D^2H)$

*** Adjusted as in Baskerville (1972)

Continued ...

Using different regressions, based on stand age and number of trees per hectare, the authors also estimated that stand component weights for regeneration 2 to 5 yr old and for three density classes chosen on the basis of the available data. These estimates are presented in the table below.

Age (yr)	Dominant height (m)	Density no. trees/ha	Component dry weights (kg/ha) Woody material	Leaves
2	1.7	160,000	4,120	2,527
		220,000	4,435	2,674
		280,000	4,674	2,785
3	2.4	110,000	4,993	2,379
		150,000	5,300	2,522
		190,000	5,534	2,631
4	3.0	75,000	6,356	2,237
		100,000	6,641	2,369
		125,000	6,862	2,472
5	3.5	50,000	8,195	2,094
		65,000	8,454	2,215
		80,000	8,660	2,310

The regressions developed for compilation of biomass yield tables were as follows for Alberta and Saskatchewan portions of the mixedwood section:

	N	Dependent	Independent	R^2	SE
Alberta	198	D	$3.3984 + 0.0139045\ H_D \ln A$	0.946	6.912
Saskatchewan	152	D	$5.9078 + 0.0139045\ H_D \ln A$	0.946	6.912

Length of rotation age is often based on the culmination of mean annual increment (MAI). For this reason, ages at which such maximums occur for different biomass components and for total above-ground tree biomass were obtained for the three site index classes (16, 20 and 24 m at 50 yr) for Alberta and Saskatchewan. These ages of culmination and the actual maximum MAI of biomass values are shown in the table on the following page with similar statistics for basal area.

Continued ...

Bella, I.E. and J.P. De Franceschi. 1980. Continued

Site index	Stem wood Age*	Stem wood MAI**	Branches & leaves Age*	Branches & leaves MAI**	Basal area Age*	Basal area MAI**
			Alberta			
16	32	1,446	26	328	19	0.924
20	30	2,309	25	485	18	1.219
24	29	3,261	24	645	17	1.476
			Saskatchewan			
16	31	1,471	23	339	16	1.003
20	29	2,310	23	491	16	1.209
24	28	3,220	22	641	15	1.537

* In years
** MAI in kg/ha; basal area MAI in m^2/ha

The greatest proportion of leaves or branches and leaves occurs at the youngest ages and steadily declines with age. Leaf percentage drops from just under 40% to about 20% from age 2 to 5 and from around 5% to under 3% between 10 and 40 yr. Conversely, there is a steady increase in the proportion of stem wood. From 10 to 40 yr the proportion of stem wood increases from 60 to 70%, and there is a corresponding drop in the proportion of biomass in bark, branches and leaves. Similar trends for other species have been observed by a number of researchers.

The relationships developed by the authors provide information for determining rotation age for aspen managed for maximum biomass production. These results indicate a rotation age of around 30 yr for fully stocked, dense aspen stands, slightly longer on poor sites and shorter on good sites. This compares quite favourably with results of other research that indicated a rotation age of about 25 yr for stands growing on relatively good sites (site index 21 m at 50 yr) in north-central Minnesota. Although optimum rotation can be taken as 30 yr for all conditions, the estimated maximum total above-ground biomass MAI ranged from 4.8 t/ha on better sites (site index 24 m at 50 yr) to 2.2 t/ha on poorer sites (site index 16 m at 50 yr).

1. BELLA I.E. and J.M. JARVIS

2. 1967

3. High total productivity of a young aspen stand in Manitoba.

4. Woodlands Review, October 1967, p. 432 and 437

5. a. Canada; Index map NM-14; Manitoba; B-15

   b. Aspen

   c. Biomass (tree)

6. Fast-growing species that reproduce readily and have desirable wood characteristics with relatively little bark will be required for short-rotation management. In this context, trembling aspen might be used because of its thin bark, rapid growth, ease of regeneration and widespread occurrence. The authors examined total productivity of young aspen in a 13-year stand about 65 km southeast of Winnipeg.

The following results were obtained for nine sample plots, all in 13-year stands, in order of increasing standing crop (above-ground portion only):

Plot no.	Above-ground green weight (t/ha)	Above-ground dry weight (t/ha)
6	38.53	17.42
8	56.33	25.46
3	68.25	30.84
5	68.73	31.07
9	82.74	37.39
4	88.23	39.88
2	88.65	40.08
1	108.00	48.82
7	112.08	50.66
Mean	79.06	35.73

The mean above-ground yield of 35.73 t/ha, dry weight, indicates that young natural aspen stands contain substantial volumes of raw material. It is conceivable that even greater production could be obtained if, at the time of establishment, treatments were carried out to minimize vegetative competition or if fertilizers were applied to increase growth.

1. **BELLEFLEUR, Pierre and Allan N. AUCLAIR**

2. 1972

3. Comparative ecology of Quebec boreal forests: a numerical approach to modelling.

4. Canadian Journal of Botany 50:2357-2379

5. a. Canada; Index maps NL-17, NL-18, NM-18, NM-19; Quebec; B.1a, B.2, B.3, B.7

   b. Nil

   c. Climate/growth (direct relationships, indirect influences, microclimate, latitude)

6. The purpose of this study was to determine species-environment relationships as a first step toward further studies on forest structure, dynamics, and productivity. Boreal forests in Quebec are comparatively moist (78 to 102 cm/yr), with cool summers and no dry season (Humid Continental, type Dfb on Köppen scale). Snow accumulation is high (75 to 150 cm/yr), compared to other areas. Within its southern and northern limits in Quebec, the growing season varies from 140 to 160 days.

Seven regions selected for study were located with respect to maximum differences in climate and vegetation. The four westernmost regions were located at about 1° intervals of latitude, as shown in the table below. Since strong temperature and precipitation differences are evident with latitude and longitude over this area some assessment of vegetation response to major climatic variations was possible.

Region	Forest section	Long. °W	Lat. °N
1	*	76.5	46.0
2	B7	76.2	47.2
3	B7	76.2	48.0
4	B1a	72.0	47.4
5	B3	75.4	49.0
6	B1a	67.5	50.0
7	B2	66.8	48.7

* South of boreal forest region, in Great Lakes - St. Lawrence region

Fifteen variables related to temperature, solar radiation, precipitation, and evapotranspiration were selected with regard to their effects on tree growth and reproduction. Data were obtained from meteorological stations closest to the geographical centres of each of the seven study regions.

Continued ...

The table below lists the growth-relevant meteorological parameters used to compare the seven regions of Quebec boreal forest. Parameters with asterisks were computed for each month of the growing season (June to September inclusive). Three year intervals were based on Canada Department of Transport data for 1965 to 1967.

Category	Parameter description	Interval (yr)
Temperature	*Monthly mean maximum temperature	3
	*Monthly mean minimum temperature	3
	*Monthly mean temperature	3
	*Monthly number of days under 0° C	3
	*Monthly number of days over 18° C	3
	Annual number of days under 0° C	20
	Annual number of days over 18° C	20
Solar radiation	Annual calorific factor (degree x day 18° C)	20
	Annual mean hours of radiation	20
Precipitation	*Monthly precipitation	3
	*Monthly number of days with precipitation over 2.5 mm	3
	Water equivalent (residual amount of snow):	
	March 31	3
	April 31	3
Evapotranspiration	Blaney and Criddle index	-
	Thornthwaite index	-

The most significant set of ecological relations in Quebec boreal forest is moisture and air drainage related to catena. Among all regions there are two distinct environments: those of lower catenas with level topography and impeded drainage and those of well-drained forest sites on upper catenas with steep (6 to 45%) slopes. Since precipitation in boreal regions of Quebec is relatively high and temperatures cool, moisture is excessive and forest growth is limited on those sites with less than adequate drainage. Moreover, much of this region was heavily glaciated with the result that pre-existing patterns of drainage were obliterated. A variety of studies on boreal forests have indicated that moisture drainage is a major vegetational determinant.

1. **BERJEY, William Grant**

2. 1974

3. Seasonal energy balance trends in the subarctic: The microclimates of a broken spruce forest and clearing, Kluane Lake, Yukon, 1970-1971.

4. University of Michigan, Ann Arbor, Mich. Ph.D. Thesis. 227 p

5. a. Canada; Index map NP-7/8/9; Yukon; B.26.d

   b. Spruce

   c. Climate/growth (microclimate)

6. This study provides a comparative microclimatic analysis of a broken spruce forest and an adjacent clearing near Kluane Lake, Yukon, during the period 1 June 1970, through 11 July 1971. Such subarctic microclimatic data, particularly for the winter season, are scarce.

In comparing the broken spruce forest and clearing microclimates the author found that:

1. Albedo and long wave radiation differences result in more positive radiation balances at the forest site than in the clearing during all seasons. This is the main reason for different energy balances at the two sites.

2. Synoptic changes in cloud cover result in large day to day differences in radiation balances at both sites by increasing incoming long wave radiation during winter, and by reducing the insolation during summer.

3. Contrary to usual assumptions, the broken subarctic forest generally does not moderate air temperatures, particularly during winter. Air temperature extremes are in fact often greater in the broken forest than in a clearing.

4. The broken spruce forest does moderate heating and cooling of the soil relative to soil in the clearing. In general, the broken spruce forest does affect microclimate within it, but not to the same degree as do closed canopy, dense forests. Because there is no well-defined forest canopy at Kluane Lake, the results are not directly comparable with microclimate studies either above or below canopies. The microclimate is treated using the forest floor as the interface while taking account of the effects of the foliage.

5. Conventional aerodynamic solutions for sensible and latent turbulent heat fluxes are of very limited utility in the subarctic.

This study illustrated that microclimates of the boreal subarctic forests and clearings are distinctly different and thus microclimates should not be generalized under one category in the forest-tundra transition region of the subarctic.

1. **BERGAN, Jarle**

2. 1974

3. Varmeklimaet i forskjellige høydesoner under bjørkeskoggrensa i Troms. [The heat effect at different vertical distances below the birch timberline in Troms]

4. Reports of the Norwegian Forest Research Institute 31.8:332-353

5. a. Norway

   b. Birch, Norway spruce

   c. Climate/growth (latitude), Climatic variation (regional, temperature), Treeline studies (climate)

6. The main objective of this investigation was to study the climatic growth factors and their influence on forest growth, regeneration and extension towards the alpine zone at two study sites. The Øverbygd station is inland (69 00 N, 19 30 E); the Lenvik study area was near the coast (69 22 N, 17 53 E). For the purposes of this study, altitudinal timberline was defined as the elevation where the distance between individual trees, which are at least 3 m high, is greater than 30 m. At both experimental areas, the forest consists mainly of birch (**Betula pubescens**) with scattered trees of Scots pine. At both study areas, the altitudinal timberline was formed by birch and was at an altitude of 500 m above sea level at Øverbygd and 310 m above sea level at Lenvik.

Three different expressions of the heat effect were used: mean maximum temperature (the mean maximum temperature for a certain period is the mean of the highest daily temperatures recorded in the period); mean temperature (the mean of all the daily means derived from 24 hourly readings); and sum of growth units. A growth unit is the heat effect produced when the temperature average for the six warmest hours of the day is 8° C. At Øverbygd the mean daily temperature for June to September, mean daily maximum temperature for June to September and sum of growth units for June to September were 9.0° C, 12.1° C and 229 growth units for the 1967 to 1972 period. At another study area in southeastern Norway, values found of 8.4° C, 13.3° C and 225 growth units were recorded at the climatic altitudinal timberline for birch. The investigations indicate that the sum of growth units for June to September is the most convenient expression when comparing data for the heat effect in mountain forests at northern and southern latitudes in Norway, at coastal and inland locations.

When temperatures of stations at the same altitude above sea level in coastal and inland areas of Troms were compared, the values did not agree very well. If the elevation was defined in relation to the vertical distance below the climatic treeline, however, the temperature conditions corresponded very well in the two different climatic areas. Preliminary results of other experiments together with the climatic observations at Troms indicate that the vertical distance between the Norway spruce and the birch altitudinal timberline is about 100 m.

1. BERGERUD, Arthur T.

2. 1971

3. Abundance of forage on the winter range of Newfoundland caribou.

4. Canadian Field-Naturalist 85:39-52

5. a. Canada; Index maps NK/NL-21/22, NM-21/22; Newfoundland; B.28a, B.28b, B.29, B.30, B.31, B.32

   b. Nil

   c. Biomass (moss/lichen)

6. The author recognized three major vegetation types: 1) forest sites that had supported closed-canopy forests prior to the most recent forest fires; 2) lichen woodland sites; and 3) subalpine sites. The forest sites had supported merchantable-size stands of black spruce and balsam fir. The lichen woodland formation consisted of a thinly scattered forest of open-grown and unpruned conifers. Black spruce and larch were the dominant species. Surrounding the conifer clumps or lone trees was a continuous and uniform carpet of reindeer lichens. This formation is recognized as the ecotone between the boreal forest and tundra. The subalpine zone, if unburned for at least 60 yr, was often characterized by climax krummholz spruce and fir.

Standing crops of lichens in the three vegetation types were determined as follows:

Vegetation type	Years since burned	Lichen standing crop (kg/ha)
Forest sites		
Red Indian Lake	36	440
Harrimans Brook	32	330
Paradise Lake	22	220
Division Lake	14	660
Cormack Lake	10	-
Miguel Mountain	10	-
Division Lake	7	-
Lichen Woodland sites		
Birchy Lake	-	13,400
Partridgeberry Hills	66	8,000
Newfoundland Dog Pond	65	5,500
Sandy Lake, Badger	57	7,280
Lower Humber River	55	5,800
Indian River	52	5,900
Crooked Lake	27	880
Island Pond	20	770
Crooked Lake	10	330
Gander River	6	-

Continued ...

Vegetation zone	Years since burned	Lichen standing crop (kg/ha)
Supalpine sites		
Interior of Avalon Pen.	-	4,400
Connoire Bay	-	2,800
Cold Spring Pond	-	2,300
Dolland Brook	-	2,300
Buchans Plateau	-	1,800
Grandys Brook	-	-
Shephensons Pond	-	1,230
Buchans Plateau	35	770

Overall forage for caribou was most abundant where forest and tundra met in the lichen woodlands. Here the scattered trees protected the shrubs and lichens from exposure but were not sufficiently dense to seriously reduce the light required by lower strata of vegetation. In addition, the scattered trees carried heavy loads of arboreal lichens.

The author indicated that forest fires would improve shrub and terrestrial lichen supplies if they caused closed-canopy forest sites to revert to lichen woodland or shrub barrens. However, fires would reduce food supplie on lichen woodland sites if such areas became permanent shrub barrens. In nine disturbed lichen woodlands investigated there was no evidence that fires had altered the sites to permanent shrub barrens; scattered spruce were common at all sites. The immediate effect of the fires was to reduce the abundance of lichens for at least 30 yr.

1. BICKERSTAFF, A. and S.A. HOSTIKKA

2. 1977

3. Growth of forests in Canada. Part I: An annotated bibliography.

4. Fisheries and Environment Canada, Canadian Forestry Service, Forest Management Institute, Ottawa. Information Report FMR-X-98. 197 p

5. a. Canada; Index maps (all in boreal region); All boreal forest sections in Canada

   b. Aspen, balsam fir, balsam poplar, black spruce, jack pine, larch, red pine, white birch, white spruce

   c. Forest growth and yield

6. This bibliography was prepared as a preliminary step toward a national estimate of the productive capacity or growth of Canadian forests. The principal index of growth used in the estimate was the mean annual increment at rotation age of natural stands of average stocking, at a level of management that assumed satisfactory regeneration following harvest or other disturbance, but little or no subsequent treatment to increase yields. From this practically attainable bench-mark level of productivity, increases from intensive silvicultural practices can be measured. The 634 references covered Canadian literature related to the increment or yields at known ages of naturally established unmanaged stands. Partial coverage was given to results from silvicultural experiments concerned with cutting methods where information on the growth of untreated stands was also provided. Some references of a summary nature were included to give access to the literature in such specialized fields as artificial regeneration, tree improvement, fertilization, or other intensive management practices.

When this bibliography was undertaken, the primary objective was to reference all published quantitative data that could be useful in making estimates of the natural growth and long-term productivity of forest conditions defined by ecological and political boundaries. In the opinion of the authors, only one province, British Columbia, has published enough information to permit a preliminary and independent estimate of long-term growth potential for broad, ecological or administrative zones within an entire province. Published inventory data in British Columbia provide, by management units, per-acre data on the actual mean annual increment at rotation age of present stands by site classes together with the areas to which they apply. Paired values such as these are lacking in almost all other publications.

Much of the Canadian literature on growth or productivity stems from research and development activities and is concerned with techniques and/or the per-acre productivity of small areas or particular forest conditions. Remarkably little of the literature deals with the

Continued ...

evaluation or description of techniques that are being practically applied by provinces or industries and how the data derived from them are used in management operations or systems. Even less published information relates to growth and productivity on a national basis.

The authors concluded that on the basis of published data, an objective, quantitative estimate of the productivity of all Canada's forest areas is impractical. For country-wide estimates of this nature, use must be made of the large amount of unpublished and heterogeneous information relating to forest inventories, growth studies and site evaluations that have been made by many organizations.

Most of the references assembled by the authors deal with productivity on a wood volume basis rather than a weight basis. Most of their references that did present data for the boreal region in terms of biomass have been annotated elsewhere in this annotated bibliography.

In addition to a subject index and a co-author index, the authors' bibliography indexes the references by Rowe's forest sections within each province. Such indexing of existing growth and yield reports, when combined with the boreal forest section index of this volume, provide the reader with a representative listing of reports on the subject of productivity in boreal forests of Canada.

1. BICKERSTAFF, A., W.L. WALLACE and F. EVERT

2. 1981

3. Growth of forests in Canada. Part 2. A quantitative description of the land base and the mean annual increment.

4. Environment Canada, Canadian Forestry Service, Petawawa National Forestry Institute, Chalk River, Ontario, Information Report Pl-X-1 136 p

5. a. Canada; Index maps (all in boreal region); all boreal forest sections

   b. Nil

   c. Forest growth and yield

6. Bench-mark data on the per hectare productivity and its areal distribution are provided for 139 ecopolitical units formed by combining the ecologically defined forest regions and sections of Canada with its ten provinces and two territories. This relatively stable data base can be grouped as required for changing technical, economic, and political purposes, and is summarized in this report. This is the second part of a two-part study. The first part was an annotated bibliography and historical review of growth and yield studies and activities in Canada (Bickerstaff and Hostikka 1977) covering over 600 published references relating mostly to unmanaged forests.

The mean annual increment to maturity for natural stands of average actual stocking was used to indicate the growth capacity of productive forest land. The latter was considered to be an indication of the long-term level of production that can be sustained by basic forest management requiring only satisfactory regeneration, protection, and harvest near rotation age. For forest management planning, the most useful index of growth or productivity is the mean annual increment at rotation age of the stands being managed. In Canada, it ranges from about 0.3 m^3/ha/yr for slow-growing stands on poor sites to over 10.5 m^3/ha/yr for very good sites. Both mean annual increment and the site quality of the tree species occupying a site are the result of many component factors such as climate, soil type, moisture, altitude and latitude which, together with such stand characteristics as age and stocking, control the basic productivity of land for forestry purposes.

The relative importance of the boreal zone, involving three separate subdivisions recognized by the authors (boreal continuous forest, boreal forest-grassland transition, and boreal forest-barrens transition) is shown on the following page on a land area basis:

Continued ...

Subdivisions of boreal forest region
(area in thousands of km^2)

Province or Territory	Boreal continuous forest	Boreal-grassland transition	Boreal-barrens transition	All*
B.C.	198	-	-	917
Alta.	420	74	6	644
Sask.	282	81	46	570
Man.	286	48	194	549
Ont.	423	-	246	885
Que.	502	-	494	1,357
N.B.	2	-	-	70
N.S.	-	-	-	52
P.E.I.	-	-	-	6
Nfld.	120	-	210	363
Y.T.	185	-	58	528
N.W.T.	125	-	667	1,665
All of Canada**	2,543	203	1,921	7,606
% national	33.3	2.7	25.3	

* This column refers to the total area of all forest regions in a given province or territory

** Excluding the land area of the arctic islands

In the boreal continuous forest, productive forest land has an average mean annual increment of 1.5 m^3/ha but there is a wide distribution of individual section averages. The total natural productivity of this major region is estimated at 220,000,000 m^3 annually or 52% of the national total.

For productive forest land in the boreal-barrens transition, field data on growth and yield applicable on an area basis are very limited. However, from fairly extensive unpublished field data in Labrador, yields from 21 to 56 m^3/ha appear to level off between 100 and 200 yr, providing mean annual increments from 0.2 to 0.4 m^3/ha with an assumed average of 0.3 m^3/ha. The estimated total natural productivity of the region, 18,000,000 m^3 annually, although constituting 4% of the national total, is not of practical significance.

In the transition zone between boreal continuous forest and grassland, commercial utilization of yields on productive forest land is negligible because of lack of markets for the low-quality forest occurring mostly on the poorer sites. However, at an estimated mean annual increment of 1.1 m^3/ha the total natural productivity of 3,600,000 m^3 annually might be sufficient to sustain biomass-energy harvesting operations using agricultural harvesting techniques for small material on short rotations.

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Bickerstaff, A., W.L. Wallace and F. Evert. 1981. Continued

The authors' summaries of average mean annual increment for subdivisions of the boreal forest were summarized as below:

Mean annual increment in subdivisions of boreal forest region (merchantable m^3/ha/yr)

Province or Territory	Boreal continuous forest*	Boreal-grassland transition*	Boreal-barrens transition**	All*** forest regions
B.C.	-	-	-	2.3
Alta.	2.2	1.1	0.4	1.7
Sask.	2.0	1.1	0.4	1.3
Man.	1.4	1.1	0.5	1.0
Ont.	1.8	-	0.6	1.5
Que.	1.7	-	0.4	1.4
N.B.	2.8	-	-	1.9
N.S.	-	-	-	1.6
P.E.I.	-	-	-	1.7
Nfld.	1.3	-	0.4	0.8
Isl.	1.3	-	1.0	1.3
Labr.	-	-	0.3	0.5
Y.T.	-	-	0.3	0.6
N.W.T.	-	-	0.4	0.5
All of Canada	1.8	1.1	0.4	1.5

* Operability Class 1 (primary supply)
** Operability Class 3 (tertiary supply, suitable only for local use)
*** This column refers to mean annual increment (m^3/ha/yr) averaged for three operability classes and for all forest regions within any given province or territory

1. BLACK, R. Alan and L.C. BLISS

2. 1980

3. Reproductive ecology of Picea mariana (Mill.) BSP., at tree line near Inuvik, Northwest Territories, Canada.

4. Ecological Monographs 50:331-354

5. a. Canada; Index maps NQ-7/8/9, NR-7/8/9; District of Mackenzie; B.23b, B.32

   b. Black spruce

   c. Climate (air masses), Climate/growth (latitude), Climatic variation (regional, temperature, precipitation), Growing season (degree day totals), Forest growth and yield, Treeline studies (growth, climate)

6. Study areas were located along a north-south transect at 133 30 W, from 40 km north of Inuvik to the community of Arctic Red River. The study transect encompassed an area within which vegetation was considered homogenous for the region. Region I (68 40 N to 68 24 N) was within the forest-tundra north of the forest line. Region II (68 24 N to 68 08 N) was the northernmost limit of open boreal forest, in which there was limited growth and reproduction of black spruce in established vegetation. Regions III and IV (68 08 N to 67 46 N and 67 46 N to 67 25 N, respectively) were those in which reliable reproduction of black spruce stands was recorded in conjunction with generally improved growth rates.

Macroclimate of the study area is transitional between the taiga, continental tundra and marine tundra climatic zones, and is a result of the interaction of major air masses. Winter months over northern Canada are dominated by continental arctic air, which retreats and modifies in summer months to become maritime arctic air or cold maritime arctic air. These modified summer air masses are associated with the Beaufort Sea and the stagnant polar ice cap. The frontal formation of these summer air masses, with maritime polar or rarely maritime tropical air, occurs commonly near the study area.

The proximity of arctic air masses at all times results in cool summers, low precipitation and steep gradients of temperature and precipitation increasing from north to south. Important macroclimatic averages are the 13.3° C July mean and -29.4° C January mean temperatures, with 260 mm average annual precipitation of which 67% is received as snow. Snow release generally occurs by 20 May and recordable snow depths (greater than 2.5 cm) generally occur by 10 October.

Climatic variation across the treeline was demonstrated by temperature differences that directly affect the length of the growing season. Degree days greater than 0° C reflected the 4° C daily mean difference

Continued ...

along the 135 km study transect. The average of degree days above 0° C for the years 1970 to 1976 was just over 1400 at the most southerly point of the transect and between 900 and 1000 at the most northerly end.

Mean tree volume was calculated for each plot and the correlation of stand density, latitude, and age examined by a stepwise linear multiple regression. Density of the stand accounted for 71% of the explained variance. Density reduced mean tree volume in both young dense stands and overstocked older stands. The log mean tree volume as a function of log density yielded a significant negative correlation which suggested interspecific interference resulting in stand thinning. This interference was probably due to root interactions.

Stand volumes were generated for each study region using the mean tree volume multiple regression and an average stand density. Stand volume calculated for Region I was overestimated tenfold when compared to field data. The calculated values represent a potential never reached due to physical damage by wind abrasion and observed tree densities lower than the assumed average density. Age accounted for most of the explained variance in dominant height and mean stand height, 89% and 88%, respectively.

Along the climatic gradient of the study area, changes in mean daily summer temperatures, length of growing season, and annual precipitation are the most important factors for reproductive success of black spruce. Temperature changes were the most prominent in this study; over the 135 km transect they resulted in a vegetational change from self-reproducing forests to forest-tundra and, north of the study area, to tundra vegetation.

Limits to vegetative growth of black spruce at treeline may result from wind abrasion or water stress. Studies of European conifers found that water stress and premature needle cast were probably caused by anatomically immature needles; the poorly developed needles were related to a shortened growing season near alpine treeline. Needle longevity for forest-tundra trees near Inuvik was reduced to 6 years, compared to 11 years for trees south of the subarctic treeline.

The authors found that average tree growth generally decreased south to north but fell short of predicted values by an order of magnitude in Region I. Annual height growth of individuals in Region I, however, was often double the annual increments from Regions II, III and IV. These trees appear to have been released from competition in the low-density Region I stands. Stand volume reductions are the subsequent result of low seedling establishment densities and deformity by ice abrasion. Therefore, tree growth at the forest tundra ecotone appears to be unrestricted by environment, except as the result of low densities of seedlings during establishment phases of forest development.

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Temperatures below 15° C, the lower cardinal limit for seed germination, are probably the ultimate control of black spruce at treeline and stand reproduction south of forest line. The relatively short period of time (5 to 8 yr) possible for establishment after a fire accentuates the precarious nature of treeline. This short period for effective seedling establishment is probably due to short seed life in cones and the apparent destruction of ungerminated seed in the soil. Consequently, the lower cardinal temperature of seed germination and limited time for establishment help explain the rapid retreat of treeline reported by Nichols (1975).

Short-term (1 to 10 yr) changes in climate could exhaust the seed population before a fire or prevent seed germination after fire and therefore result in large areal changes in vegetation. Major changes in tree cover over large areas may reflect only minor and short-term changes in climate near the forest line.

Climatic reconstruction could possibly be based on the climatic requirements for reproduction of black spruce. Estimated minimum average temperatures for reproduction of black spruce in the District of Mackenzie are 11°, 14° and 11° C for June, July and August, respectively. These are temperatures estimated from 40 km south of modern treeline and suggested treeline is out of equilibrium with modern climate. Temperatures of 9.5°, 13° and 10° C are minimum estimates below which no successful establishment would be expected.

Degree day values (greater than 0° C) of 1200 and 1330 are upper and lower estimated limits for no establishment and reliable establishment, respectively, for black spruce. These estimates, based on temperature control of seed germination and germination potential, provide a basis for climatic reconstruction, if caution concerning environmental variability is incorporated.

Qualitative information to support the out-of-equilibrium position of treeline was found by the absence of reproduction following burning in Regions I and II, where stands failed to regenerate after a fire occurred in old stands that had originated prior to 1850. These old stands probably represent a northward pulse of forest line in response to a warming trend during the 18th and 19th centuries (Nichols 1976). Modern stands reliably regenerate in Regions III and IV near Inuvik, providing the burn interval is of sufficient length to permit seed production of the new forest.

1. BLASING, T.J. and H.C. FRITTS

2. 1975

3. Past climate of Alaska and northwestern Canada as reconstructed from tree rings.

4. IN: G. Weller and S.A. Bowling, Editors, Climate of the Arctic, Twenty-fourth Alaska Science Conference. p. 48-58

5. a. Alaska; Canada; Index Maps (all in Yukon and District of Mackenzie); Yukon, District of Mackenzie; all boreal forest regions in Yukon and District of Mackenzie

   b. Nil

   c. Climate/growth (direct relationship), Climatic change (dendrochronology)

6. Ten different types of tree-growth anomaly patterns were identified in Alaska and northwestern Canada for the period between 1800 and 1939. Climatic conditions inferred from the growth anomalies of arctic trees were compared to circulation anomalies over the Arctic as reconstructed from arid-site trees in southern Canada and the United States.

Both tree ring data and climatic data suggest that during the 19th century the summer storm track in the region of Alaska was displaced north of its present day 'normal' position and that the Pacific subtropical high was also displaced northward so as to be particularly strong in the Gulf of Alaska. The authors have reconstructed pressure anomaly patterns for North America west of 80° W and have inferred from them that in the central and eastern parts of the continent the summer storm track during the 19th century was displaced south of its 20th century normal position. The overall reconstruction implies a more meridional circulation in the 19th century than in the first half of the 20th. This pattern should not be confused with the pressure pattern in which a normal displacement of the storm track is suggested at all longitudes over North America, the Pacific subtropical high is not particularly strong in the Gulf of Alaska, and the anomalous circulation is relatively zonal (Blasing 1973).

The anomalies of pressure used in this report represented only the July-August period. Some inconsistencies can result between these pressure anomalies and those of growth whenever conditions in June become limiting to growth.

Other variables that may be of value in the reconstruction of past climatic conditions were described. Timing of the movement of the Pacific subtropical high into its 'summer' position which usually takes place during the latter part of June, might have a sufficient relationship with tree-growth patterns to allow identification of those years when the timing of that event is anomalously early or late. It should also be possible to calibrate the arctic and subarctic tree ring data directly with pressure as was done for the arid-site trees to the south.

1. BOLIN, Bert

2. 1977

3. Changes of land biota and their importance for the carbon cycle.

4. Science 196(4290):613-615

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree), Climate (carbon dioxide levels), Climate/growth (indirect influences), Climatic change (hypotheses), Climatic variation (temporal)

6. It is well established that the carbon dioxide content of the atmosphere is increasing. Observations at the South Pole, on Hawaii, and in the upper troposphere of the Northern Hemisphere are available for almost 20 yr. The increase has been about 16 parts per million (ppm) - from 311 ppm in 1957 to 327 ppm in 1975 - that is, about 5%.

In recent years several attempts have been made to assess the net primary production and the total mass of land biota. The table below is an extract of a summary presented by Whittaker and Likens, which the author believes is probably the best estimate available so far. The figures refer to the year 1950. For comparison, Bazilevich and co-workers give about 50% larger figures.

Vegetation type	Area ($10^6 km^2$)	Total net production ($10^9 t/yr$)	Total biomass ($10^9 t$)
Tropical rainforest	17.0	15.3	340
Tropical seasonal forest	7.5	5.1	120
Temperate forest, evergreen	5.0	2.9	80
Temperate forest, deciduous	7.0	3.8	95
Boreal forest	12.0	4.3	108
Subtotals	48.5	31.4	743
Woodland and shrubland, savanna	23.0	6.9	49
Temperate grassland	9.0	2.6	6.3
Tundra and alpine	8.0	0.5	2.4
Desert and semidesert	18.0	0.6	5.4
Extreme desert, rock, ice, sand	24.0	0.04	0.2
Cultivated land	14.0	4.1	7.0
Swamp and marsh	2.0	2.2	13.6
Lake and stream	2.5	0.6	0.02
Totals	149.0	48.3	827

Continued ...

Bolin, B. 1977. Continued

In the 20 yr that have seen such a marked increase in atmospheric CO_2, the net change in forest cover in developed countries is probably less than 1%, which is insignificant in relation to the large CO_2 changes. However, the use of forests in some of these countries has changed considerably during the 20th century. Particularly in Europe, forests were previously used extensively for cattle grazing. This was especially the case for deciduous forests, but in Sweden boreal forests were also used in this way. During the last 50 yr this practice has been almost completely abandoned, and the forests have grown more dense. As an example, from the middle of the 1920's until about 1970, the total amount of timber in Swedish forests increased by almost 40%. A 10% increase of the biomass of Swedish forests represents an increase of carbon content by 0.5×10^9 t. To some extent this effect is counteracted by the prevention of forest fires. The author concluded that the changes of forests in developed countries do not now represent a significant flux of carbon to or from the atmosphere.

For the developing countries as a whole, about 0.12×10^6 km^2 of natural forest is cleared and burned every year. It is estimated that the areas of closed forests in the developing countries will have decreased by 20 to 25% by the turn of the century if this trend continues. If we assume that all of the biomass in these forests burns (20 kg of carbon/m^2) we arrive at an annual input of 1.5×10^9 t of carbon into the atmosphere in the form of carbon dioxide. This is likely to be an overestimate, partly because not all of the living biomass burns and partly because some of these areas again become covered by vegetation, although usually not forests.

1. BOLIN, B.

2. 1980

3. Climatic changes and their effects on the biosphere.

4. World Meteorological Organization. WMO - No. 542. 49 p

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb, moss/lichen), Climate/growth (direct relationships, indirect influences), Climatic change (hypotheses), Climatic variation (temporal)

6. The author began this detailed review by stressing that the dependence of various biomes on climate is more subtle than one expects at first sight since other environmental factors also play a role. Further, a biome is not necessarily in balance with its environment. Even if the climate does not change, the basic characteristics of the ecosystems may; for example, the soil may gradually be modified under the influence of vegetation. The relative frequency of species may change due to internal competition, while the ecosystem develops towards a climax state, but also due to migration of new species into its domain. Even if static relationships between climate and vegetation are useful as first approximations, a more careful analysis is sometimes desirable when considering the question of how climatic changes may affect the biosphere now and in the future, particularly when they are rapid.

The author brought out another point that is not often mentioned in discussions of climate-vegetation relationships, namely that present-day climate is determined to a considerable extent by the existence of life on land and in the sea. In a treatment of the effects of climatic changes on the terrestrial and marine biota this mutual interplay should be considered since it may well have been important for the evolution of their present characteristics. Some investigators have even advanced the hypothesis that the biosphere has been developing in such a way that the global mean temperature has remained more constant over geological time than one would expect to have been the case for a lifeless planet.

Variations within the different biomes are large and the mean values of net primary production and biomass probably have an uncertainty of 20 to 40%. Further, their spatial extensions are not simple to determine accurately due to the mosaic character of their distribution. It is even more difficult to estimate the amounts of organic matter in the soil, since the depth to which it may extend varies greatly from one biome to another. For example, in cold climates where bogs form due to the very slow decomposition rate, one may find layers of organic material extending to a depth of 10 m or more.

This review contained estimates from the literature for net primary production, leaf surface area, biomass and soil organic matter content

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from which data for the world's boreal forest and the total land area are listed in the table below:

	Total boreal forest	Earth's Total land area
Area (10^6 km^2)	12.0	149.0
Net primary production, dry matter		
normal range (g/m^2/yr)	400–2000	–
mean (g/m^2/yr)	800	782
total (10^9 t/yr)	9.6	117.5
Net primary production, carbon (10^9 t/yr)	4.3	52.6
Mean leaf surface area per unit land area (m^2/m^2)	12	4.3
Biomass, dry matter		
normal range (kg/m^2)	6–40	–
mean (kg/m^2)	20	12.2
total (10^9 t)	240	1837
Total carbon in biomass (10^9 t)	108	827
Total carbon in detritus and soil		
mean (kg/m^2)	20.6	10.2
total (10^9 t)	247	1515

The four major forest biomes of the earth's surface contain almost 90% (740×10^9 t) of all carbon in living matter on land, while their net primary production is about 60% of the total value for the terrestrial biota. The mean turnover time for carbon in forests is thus about 22 yr as compared with 16 yr for the land biota as a whole. The mean turnover time for carbon in the form of wood in temperate forests is about 50 yr while in tropical forests it is perhaps somewhat less. Savannah, temperate grassland and tundra, on the other hand, have turnover times of living organic matter of only about 4 yr. The tendency for a slower turnover rate of living matter in cold climates as compared with the tropics is even more pronounced for dead organic matter in the soil. The mean turnover times for carbon in soils of tropical, temperate and boreal forests are 18, 21 and 42 yr, respectively, and the figures for savannah, temperate grassland and tundra alpine land are 9, 72 and 350 yr, respectively.

Lieth has presented graphs showing net primary production in various parts of the world as a function of temperature and rainfall. Since

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there is a marked correlation between temperature and rainfall, one cannot directly determine their relative role for the net primary production. There is considerable scatter of the data points around the curves which describe the best fit of net primary production as a function either of temperature or precipitation. This is natural, since many other factors also influence the rate of photosynthesis. Even when deriving a multiple variable regression equation using a higher-degree polynomial of both temperature and precipitation, there is considerable variance. The two most important additional factors that need to be considered are probably light and availability of nutrients. Most well-developed ecosystems have been able to establish internal cycles that permit repeated use of the crucial nutrients required for growth. Various processes in the soil are able in this way to maintain high productivity. In regions of excess precipitation and where there is substantial runoff, some losses cannot be avoided. The maintenance of adequate nutrient resources therefore depends on the capability of some plants to fix nitrogen from atmospheric nitrogen in symbiosis with bacteria and algae, the weathering of the inorganic constituents of the soil and the supply from the atmosphere by rain or direct deposition. For this reason wet bogs often have lower primary production than would otherwise be expected.

Biological production, both on land and in the sea, depends upon the simultaneous availability of carbon (carbon dioxide in the atmosphere, and carbonate ions in the sea), water, oxygen and nutrients, of which nitrogen, phosphorus, sulphur and certain trace metals are the most important. In the process of photosynthesis and the following biochemical reactions in which organic matter is formed, the different elements are needed in rather fixed proportions. In this way the different cycles become coupled and changes in one of them often imply changes in the other. The author reviewed several of these cycles with particular emphasis on those processes and circulations that might be influenced by climate and climatic changes.

In regard to the carbon cycle, terrestrial primary production obviously depends on the amount of synthesizing matter, but it cannot be assumed to be directly proportional to the amount of carbon dioxide in the air. The response of the global terrestrial ecosystem to an increased atmospheric carbon dioxide content is, in fact, not known but, based on greenhouse experiments, it is generally believed to be somewhat enhanced by it. It is obviously difficult to qualitatively analyse in a conclusive way the behaviour of the carbon cycle, particularly the question of the likely impact on the biosphere of an increasing amount of carbon dioxide in the atmosphere due to fossil-fuel combustion. Even numerical models are still rather inconclusive, mainly because of poor knowledge of the mechanisms on a possible response of terrestrial primary production and the exchange of the intermediate waters with the ocean surface.

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The author estimated that a lowering of temperature by 4° C and an associated decrease of evaporation and rainfall by 15 to 20% (based on the assumption that the temperature changes in the tropical and subtropical latitudes are of primary importance in this regard) would reduce the primary production by 20 to 25% as compared with conditions today, that is, a reduction to 40 to 44 x 10^9 t/year.

The annual fixation of nitrogen by land plants is rather small (less than 10%) compared with the amount of nitrogen annually used in the process of primary production. An approximate balance had been established by the natural biomes between this source and denitrification and return of nitrogen gas and nitrous oxide to the atmosphere. The nitrogen cycle gives a good insight into the ways that various parts of the biosphere are interconnected by the motions of air and water and various biogeochemical processes. There is usually also a slow net transfer from land to sea, which is part of the slow geological processes of erosion and sedimentation. This is true for most minerals and is the case for the important nutrients, phosphorus and calcium. These examples indicate that there is a complex web of interactions in the global ecosystem. A change of climate, particularly temperature and rainfall, will change the distribution of biomes and thereby also many details of the patterns of fluxes and interactions. Even though the changes locally and regionally may be large, the overall characteristics of the biosphere change comparatively slowly because of the slow response of the oceans and also many soils.

To understand the dynamics of the terrestrial ecosystem and its role in the carbon cycle, it is helpful to estimate the amount of carbon annually fixed by photosynthesis and contained in biomass and soils at various stages since the last glaciation. Such estimates are obviously approximations. For the boreal forest, the author estimated that the present area is 12.0 x 10^6 km^2 compared to 13.0 x 10^6 km^2 at the end of the Middle Ages (1500 A.D.) and 9.5 x 10^6 km^2 at the peak of the last glaciation about 20,000 yr BP. The author estimated net primary production, terrestrial biomass and soil carbon at the peak of the last glaciation, at the end of the Middle Ages and at present as follows:

Year	Net primary production, carbon 10^9 t/yr	Carbon in biomass 10^9 t	Soil carbon 10^9 t
20000 B.P.	44	710	1485
1500 A.D.	56	915	1570
1975	53	827	1515

The table above indicates that a larger change in net primary production and biomass than in detritus seems to have taken place from the time of glaciation to recent times. This is a result of the comparatively large

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accumulation of detritus in cold climates (tundra) compared with tropical latitudes. The most important reason for the lower amount of carbon in the soil at the peak of glaciation is effective removal by the expanding ice sheets. The much smaller rate of net primary production also depends on lower temperature, while the decrease in biomass is primarily due to a substantially smaller area being covered by forests. The estimates in the preceding table also show an increase in the total amount of organic carbon in the biomass and soil by about 300 x 10^9 t from glacial to interglacial times and a decrease of about 150 x 10^9 t due to man's activities during the last few hundred years. These changes have, however, been rather slow in comparison with the turnover time of the ocean and it is therefore not likely that significant changes in the atmospheric carbon dioxide concentration would have occurred until the beginning of the 20th century.

1. BORISOV, A.A.

2. 1965

3. Climates of the U.S.S.R.

4. Edited by C.A. Halstead, translated by R.A. Ledward, Aldine Publishing Company, Chicago. Originally published 1959. 255 p

5. a. U.S.S.R.

   b. Mil

   c. Climate (air masses, precipitation, temperature, insolation)

6. The forest zone that includes an enormous area equal to almost half of the U.S.S.R., may be divided climatically into: (a) the taiga zone and (b) the zone of mixed and deciduous forests. The main climate-forming factors of the forest zone are radiation conditions, the rapidly varying circulation of the atmosphere which is peculiar to temperate latitudes, its continental position and the enormous areas of forest.

In an average year the forest zone receives from 40,000 cal/cm^2 (taiga) to 55,000 cal/cm^2 (deciduous forest) of solar heat on a horizontal surface - approximately twice as much as the Arctic but only half as much as subtropical latitudes. The amount of heat received is sufficient for the growth of coniferous forests in the north and deciduous forests in the south. The intense circulation of the atmosphere in temperate latitudes maintains thermal conditions and supplies the moisture needed for growth of forests.

The most frequent alternation of arctic air masses with those of temperate and subtropical latitudes takes place in the forest zone. Here the characteristic instability of the atmospheric circulation is closely related to a succession of anticyclones and depressions, to frontogenesis and the transformation of air masses. Anticyclonic types of weather are very characteristic of the intra-continental taiga near semi-permanent high pressure areas, but depressions pass from the Atlantic along the periphery of the Azores maximum and through the trough of the Iceland minimum, which corresponds to the position of the main frontal zones in winter and summer. The isoline of the stable snow cover and the January -3° C isotherm provide a good indicator of the main extent of their influence and a good boundary between eastern and western regions of the forest zone, passing to the west of Moscow.

The summer circulation is dominated by passage of Atlantic depressions and the transformation of different air masses. During the transformation of air masses there is usually only partly cloudy weather with a rise in the temperature and a fall in the relative humitidy. But the passage of depressions is characterized by colder weather, greater cloudiness and strong winds and so delays and interrupts the more favourable processes of air mass transformation. It is, therefore, no

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mere chance that with the decrease in the frequency of depressions to the east of the Moscow meridian more than 50% of all summer days, from July to August, have a mean daily temperature of not less than 20° C (during mass air transformation), whereas days with a temperature of not more than 20° C prevail to the west. An influx of arctic air, which greatly reduces temperatures in the whole zone, and particularly in the taiga, occurs from time to time in the summer. Depending on the routes followed by anticyclones and depressions, weather conditions in any part of the forest zone are extremely variable, and at any one place spring or autumn may equally likely be rainy or dry, warm or only moderately warm.

Precipitation maxima occur in the taiga in July or August, the time of the greatest evaporation for the forest surface. Autumn precipitation, associated with Atlantic depressions, is considerable in the western part of the taiga but there is a minimum of precipitation in winter, when arctic and continental processes invade the taiga. The continentality of the climate increases from west to east. The taiga of the northwestern region is characterized by extremely changeable weather, by the frequent passage of depressions and by a severe, cold winter, as well as by great cloudiness and a wet, cool summer. In winter, the prevailing southwesterly and westerly airstreams bring with them precipitation and even warmth. Therefore, at 60 N in the eastern Gulf of Finland the mean temperature is -7° C in January, whereas at the same latitude in Yakutiya it is -40° C.

Floods are a factor that can set back biomass accumulation in forests that develop on alluvial sites in the taiga. The author described the following meteorological conditions that contribute to floods:

1. Powerful depressions that pass across the Baltic Sea from the northeast when there is a low pressure area over Finland.

2. The formation in the Baltic Sea area (to the rear of the main depression) of a small but vigorous secondary depression which must pass along the Gulf of Finland or to the north of it.

3. The approach of a high pressure system from the northwest behind a main or secondary depression and the strengthening of this high pressure system over the Scandinavian Peninsula.

In all these cases suitable conditions are created for a rise in the water level in the Aland Sea, from which a storm surge moves into the Gulf of Finland, causing a rise of water in the Neva River.

The influence of the Baltic Sea on the climate of the northwestern taiga region is great; it causes warmer winter temperatures and smaller daily and yearly ranges of temperature. Coastal areas are colder than inland areas only in April and May. Summer in the northwestern taiga is comparatively short and cool, but there is plenty of light. The

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Borisov, A.A. 1965. Continued

frost-free period varies from 90 to 120 days, diminishing northwards. The multiplicity of lakes, which cool their environs, hinders the summer heating of the land over much of this area, since much of the heat is expended in the melting of ice and snow and in evaporation.

The taiga of the northeastern region is distinguished by the great continentality of its climate, a prevalence of anticyclonic weather, severe winters with heavy snowfall, moderately warm summers, the sudden onset of spring, and by recurrent cold spells. In comparison with the taiga of the northwestern region, the number of depressions is much less, especially during the warm half of the year.

The west Siberian taiga is characterized by an intense interchange of air masses, arriving from both the Atlantic and the Arctic together with the continental air of anticyclones formed in Siberia. The strong continentality, severe winters, thick snow cover, sudden onset of the seasons and frequent cold waves are distinctive features of the climate of the taiga in this region. The low precipitation in the west Siberian taiga is caused by its remoteness from warm seas and by the low mean annual temperature which reduces the moisture capacity of the air.

The taiga of the east Siberian region stands out sharply amongst the areas of the U.S.S.R. from a climatic point of view. The marked continentality of its climate, prevalence of anticyclonic weather conditions, lack of wind, cold waves, very frosty and severe cloudless winters, permafrost, hot summers, temperature inversions, the sudden onset of seasons and a high insolation in summer which allows the cultivation of watermelons near Yakutsk, combine to make the climate of Yakutiya one of the most amazing in the world. Bearing in mind that the northern and far eastern seas freeze in winter, and that mountain chains separate them from consideration, the negligible role of these water bodies in the moisture supply of the taiga and their slight cooling influence in summertime is clear. Neither Atlantic nor Pacific air often reaches the lower layers of the atmosphere of the east Siberian taiga, so that arctic air masses appear as the main climate-forming factor. The mainland is also strongly heated in summer. At Yakutsk the mean July temperature (19° C) is even somewhat higher than at Moscow, which lies more than six degrees further south. But at Yakutsk cold waves can lower the temperature by 10 to 12° C as compared with only 5 to 6° C at Moscow. The daily fluctuations are also great in the east Siberian taiga, with temperatures frequently falling almost to 0° C before sunset. Central and southern parts of this region are free from night frosts only in July. However, the average July temperature at Yakutsk is 19° C; nowhere else at this latitude is there such a high temperature. The absolute maximum temperature may reach 39° C.

1. BOTKIN, Daniel B.

2. 1977

3. Forests, lakes, and the anthropogenic production of carbon dioxide.

4. Bioscience 27:325-331

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels), Climate/growth (direct relationships)

6. It is well known that green plants grow better in air that has been enriched in carbon dioxide. It is the practice in some greenhouses to burn gas to provide both heat and carbon dioxide to improve yield. Thus, under at least some common conditions, the rate of photosynthesis is limited by the rate of carbon dioxide uptake, as well as by light intensity or other environmental conditions. This observation has two implications regarding the increase in atmospheric carbon dioxide concentration that accompanies the burning of fossil fuels and other anthropogenic activities: first, the increased carbon dioxide concentration of the atmosphere may affect the primary productivity of ecosystems, and second the biota and their products may provide important sinks for carbon dioxide.

Unfortunately, very few quantitative studies detail the exact change in the rate of photosynthesis or net growth for individual species accompanying a specified change in CO_2 concentration. The few existing studies suggest that the effects on single plants or monocultures can be great. No published reports exist concerning the response of a natural mixed-species, mixed-age community of perennial terrestrial vegetation. Thus, a consideration of the effects on natural ecosystems of a change in atmospheric CO_2 concentration must be approached indirectly.

The author stressed that it is dangerous to extrapolate from the response of a greenhouse plant to agricultural or silvicultural crops or to natural ecosystems. The well-watered, well-fertilized, well-illuminated greenhouse plant is subject to no other external growth limitations; so it is not surprising that the rate of carbon fixation of such a plant may be limited by CO_2 concentrations. When other factors are not limiting, the rate of photosynthesis of a leaf is controlled by the rate at which CO_2 can diffuse into the plant cells. In contrast, plants growing under natural conditions are often restricted by other factors. For terrestrial vegetation the principal short-time varying factors are temperature and moisture.

The authors carried out simulated experiments that suggested the following interpretations. If the CO_2 enrichment effect of an increase

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Botkin, D.B. 1977. Continued

in CO_2 concentration were uniform across species, then unless the effect of the CO_2 increase is sufficient to enhance the annual growth of each tree approximately 50% above normal, changes probably would not be observed in the productivity or biomass of the forest. Changes in net forest productivity would occur at this or higher levels for early stages in succession.

The author concluded that extreme CO_2 enrichment may have a significant effect on primary production and could increase the standing crop of forests, and such an increase could potentially represent a short-term carbon sink. On the other hand, this potential is not and probably will not be met, as man's activities are probably reducing biomass more rapidly than the biomass might increase.

1. BOUGHNER, C.C.

2. 1964

3. The distribution of growing degree-days in Canada.

4. Department of Transport, Meteorological Branch, Toronto. Canadian Meteorological Memoirs No. 17. 40 p

5. a. Canada; Index maps (all in boreal region); All boreal forest sections in Canada

   b. Nil

   c. Growing season (degree day totals, frosts)

6. To assess the suitability for plant growth of temperature conditions within a growing season, a system of accumulated temperatures or growing degree-days has been developed. This report presents accumulated degree days above 42° F (5.6° C) calculated over a 10-yr period for more than 200 Canadian stations. Growing degree-day statistics are presented in tabular and graphical form on an annual basis as well as for the effective growing season and frost-free season. As a measure of the restrictive effect of frost on the growing season for frost susceptible crops, the concept of the "freeze-free index" has been developed.

Under conditions of adequate light intensity, light duration and available water supply, temperature becomes the dominant control over plant growth. However, even with temperatures adequate for plant growth there are a number of limiting temperature factors that may influence crop production: a) length of frost-free season; b) length of season with favourable temperatures to allow the crop to reach maturity; c) occurrence of unfavourably high or low temperatures during the growing season which may hinder proper development of crops or cause injury or death to the growing plants; d) severe climatic conditions during the dormant season which may damage or kill plants; and e) occurrence of temperature conditions favourable to the development of injurious diseases or insect pests.

According to the heat unit theory, a plant requires a definite amount of heat to reach certain stages in its development. Only part of the heat received every day is used, since a minimum amount of heat is required before growth takes place. This means that a basic temperature exists below which plants will not develop, each plant having its own base or threshold temperature. The amount of effective growth heat accumulated during the day is obtained by subtracting this plant base temperature from the mean temperature for the day. This figure is called the "growing degree-day" accumulation or "heat" accumulation for the day. Growing degree-days may be accumulated for a week, a month, a season, or until the plant is matured.

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The growing degree-day theory is based on the following assumptions that are not strictly accurate: there is only one base temperature throughout the life of the plant; day and night temperatures are equally important to plant growth and thus no account is taken of latitudinal effects; the plant response to temperature is linear over the entire temperature range; and other meteorological elements do not affect the number of growing degree-days required to mature the plant. A number of investigators have attempted to improve the procedures for evaluating the accumulation of heat units by making certain adjustments for different parts of the temperature scale. Other investigations have indicated that a maximum temperature exists beyond which plants do not grow.

Nature has provided for three main exchanges of energy between the plant and its environment: 1) radiation exchanges; 2) evaporation heat losses and condensation heat gains; and 3) sensible heat transfer with the atmosphere. Growing degree-days above an appropriate base temperature are a more or less direct measure of only the last of these three mechanisms. However, they may serve as an indirect index of the other two heat exchanges.

If the mean temperature for a given day is t° F, then H, the number of growing degree days above a base temperature of 42° F is given by:

H = t - 42° for t equal to or greater than 42° F
= 0 for t less than 42° F

Using this formula, growing degree-days may be calculated for any desired period. This method has the advantage of being very simple and direct to apply.

It is recognised that growing degree-days resulting from isolated warm days in advance of the beginning of growth in spring make no effective contribution to the plant growth if they are followed by periods of low temperature. Similarly, warm days after the end of the season of growth contribute nothing to the crop. In evaluating the number of growing degree-days during the effective growing season, it was arbitrarily decided to begin the accumulation following the last period of five consecutive days, each of which had mean temperatures below 42° F. At the end of the season the count was stopped with the day preceding the first occurrence in autumn of a period of five consecutive days, each of which had a mean temperature lower than 42° F.

In analyzing the data it was observed that while the beginning and ending of the effective growing season may vary rather widely from year to year, for most stations in the agricultural areas of Canada, the transition through the 42° F daily temperature zone in any particular year is quite rapid in both spring and autumn. This implies that once the temperature reaches a mean of 42° F in spring, the trend upward usually continues without sustained retreats below this level. A similar situation occurs in autumn at the end of the effective growing season. Thus, the average

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date of the beginning of the effective growing season corresponds closely with the average date in spring when 42° F is reached on the temperature curve. Similarly in autumn, the end of the effective growing season corresponds closely to the average date when the temperature falls to 42° F.

To obtain a measure of the effect of restriction on the growing season imposed by frost, the ratio of accumulation of growing degree-days during the frost-free season to the annual total accumulation was calculated. This was designated as the freeze-free index (F) where:

$$F = \frac{\text{total growing degree days in frost-free season}}{\text{total annual growing degree-days}}$$

The freeze-free index gives an indication of the percentage of annual growing degree-days that are available for production of frost-susceptible crops at any location. It was recognized that for some plants the freeze-free index has no particular significance.

The author stressed that the influence of weather on plants is complex and it is therefore unreasonable to expect to find simple direct relationships between weather and plant growth. However the overall development of many plants follows a remarkably close relationship with temperature. The relationship between soil temperature and plant growth may well be more direct than that between mean air temperature and hence the growing degree-days accumulated on the basis of air temperature may be too high during the early part of the season.

1. BRAMRYD, T.

2. 1979

3. The effects of man on the biogeochemical cycle of carbon in terrestrial ecosystems.

4. IN: B. Bolin, E.T. Degens, S. Kempe and P. Ketner, Editors, Scope 13, The global carbon cycle, John Wiley & Sons, Toronto. p. 183-218

5. a. Northern hemisphere

   b. Mil

   c. Climate (carbon dioxide levels)

6. The author surveyed various terrestrial ecosystems with respect to carbon flow in and out of the individual system, with emphasis on tropical, temperate and boreal forests. It can be shown that there have been significant reductions in the standing crop of biomass in the world's forests; furthermore, oxidation of soil organic matter is accelerated inasmuch as this reduction is not matched by an increase in the rate of photosynthesis in virgin forests; thus the CO_2 released by man's 'cultivating' activities should ultimately end up in the atmosphere or the ocean.

The decay of soil organic matter is one of the largest CO_2 inputs to the atmosphere. Recent data, such as the FAO-UNESCO world soil map indicate that the amount of soil organic carbon in the world is about $3{,}000 \times 10^{15}$ g, with organic carbon content based on a soil depth of 1 m. The largest quantity of litter and surface humus is found in shrubby tundras (0.84×10^{12} g/m^2) followed by spruce forests in central, southern, and northern taiga (0.45×10^{12}, 0.45×10^{12}, and 0.30×10^{12} g/m^2, respectively). Broad-leaved forests have about 0.15×10^{12} g/ha, closely followed by subtropical forests with 0.10×10^{12} g/ha. The steppes often have about 0.062×10^{12} g/m^2. In tropical rain forests, the amount of litter and surface humus is very small, only about 0.020×10^{12} g/m^2. In savannas it is even smaller, about 0.013×10^{12} g/m^2.

The author speculated on the effects of synthetic fertilizers on accumulation of carbon in the world's forests. The increased growth of trees as a result of fertilizing will lead to an earlier cutting. Thus, the real accumulation will not likely increase to any larger extent. Nitrogenous fertilizers also result in an increased mineralization of the organic matter in the soil.

Peat accumulation is a mechanism of CO_2 removal rarely discussed. It is one of the few forms of soil organic matter accumulation that can be easily measured; current data indicate a rate of peat accumulation at about 300×10^{12} gC/yr or about one-third of that released by

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cultivation of new lands. This estimate of carbon accumulation by peat is based on the following data: 3.3×10^6 km^2 of wetlands of the world, an assumed density of 0.2 g/cm^3 for peat, and 50% carbon content of peat on a dry weight basis. Moore and Bellamy (1973) estimated that the world's peat resource is about 230×10^6 ha covered by 330×10^{15} g of organic matter. This would correspond to about 165×10^{15} gC.

The author indicated that the estimate of the annual peat accumulation rate as 1 mm/yr is probably an overestimation. A more relevant figure would be a global average of 0.5 mm/yr. Most estimates of 1 mm/yr are probably based on research on mires in central parts of Europe and the United States. Mires in cold regions usually have a much lower annual accumulation. This is due not only to the climate, but also to the large water-pool systems on these mires. The average for Sweden is 0.5 mm/yr. The mires have a very high productivity in the southern parts of Sweden, but perhaps only an average increase of about 0.2 mm/yr in the northern parts. The author thought that these same peat accumulation rates should also apply to peatlands in the large boreal areas in North America and the U.S.S.R.

Growth in the height of the peat-cover has varied considerably during different climatic periods. At the end of the climatic optimum it was only 0.2 mm/yr. A general feature is the increase in the rate of peat formation during the past 3,000 yr. Pakarinen (1975) estimated the global peat accumulation of temperate and boreal peatlands at about 135 to 270×10^{12} g dry weight (67.5 to 135×10^{12} gC), which is only a small percentage (less than 5%) of the current annual CO_2 emission from fossil fuels.

The peat-covered area (peat depth more than 0.5 m) in Europe is about 4% of the total land area. The corresponding values for other continents are: for Asia 11%, North America 0.6%, South America 0.13%, Africa 0.18% and Australia 0.04%. The conclusion that can be drawn is that most peat accumulation is found in boreal parts of the world. There are, however, peatlands in temperate latitudes of both the northern and the southern hemispheres. The author, citing data from Bellamy and Moore (1973), listed the following areas of peatland for countries that include the circumpolar boreal forest: Canada, 129,500 x 10^3 ha; U.S.S.R., 71,500; Finland, 10,000; U.S.A., 7,500; Norway, 3,000; and Sweden, 1,500 x 10^3 ha.

The author concluded that due to exploitation of terrestrial ecosystems by man, the outflow of carbon to the atmosphere has increased. In tropical rain forests, having the highest net primary production of all ecosystems, clearcutting and burning have destroyed large areas of forest land. In addition to rapid oxidation of the biomass, the photosynthesizing capacity has decreased on a global scale. Also in

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Bramryd, T. 1979. Continued

temperate and boreal forests, new forestry techniques could probably cause a net outflow of carbon compared with virgin forests. This would in particular be the case if plans for whole-tree utilization are realized. Very little biomass is then left in the forest to form soil organic matter. Clearing of forests to create new agricultural lands has also reduced the pool of carbon in the world's forests.

New agricultural methods such as deeper ploughing have increased the mineralization rate of accumulated organic matter. To claim new forest and agricultural areas, there are plans to drain large areas of peatland. When these areas are used for agricultural purposes, the new aerobic conditions and the intensive mixing of the peat, when ploughed, will rapidly increase the mineralization rate. Due to the search for new energy sources, there are also plans to exploit large peat areas for fuel production. This might have serious effects as the organic matter in peat becomes rapidly oxidized. The accumulating capacity of carbon is further reduced when peatlands are destroyed.

1. BRAY, J.R.

2. 1965

3. Forest growth and glacier chronology in north-west North America in relation to solar activity.

4. Nature 205:440-443

5. a. Canada; Index map NM-11; British Columbia

   b. Spruce

   c. Climatic change (hypotheses, dendrochronology, proxy data)

6. The author found a correlation between mean yearly sunspot number per decade and bole growth per decade in Engelmann spruce from the Yoho River valley in British Columbia. As shown by data in the table below, mean forest tree growth decreased with decreasing solar activity for various sunspot activity periods.

Sunspot activity period	Mean yearly number of sunspots per period	Mean sunspot cycle length (yr)	Mean bole basal area increase (cm^2/yr)	Number of glacial advances*
1914-1964	62	10.2	9.3	2
1756-1798	57	9.4	9.8	5
1834-1878	56	10.2	9.1	4
1724-1755	48	10.7	9.0	3
1611-1655	—	11.2	9.0	3
1879-1913	35	12.1	8.9	7
1656-1723	22	11.5	8.7	10
1799-1833	26	13.9	8.7	13

* allowing for a 40% lag time

The decrease in forest tree growth from 9.3 cm^2/yr for 1914-1964 to 8.7 cm^2/yr for 1656-1723 and 1799-1833 was considered to reflect growing season temperature, with more tree growth likely to occur during a longer and warmer growing season and less growth to occur during a shorter and colder season. There is, therefore, indirect evidence that summer temperatures in the Yoho area may be related to solar activity, with higher temperatures occurring during periods of greater sunspot number. Yearly world temperature patterns since 1750 have also been tentatively related to sunspot activity. The recent demonstration that atmospheric temperature above 300 km increases with higher solar activity may provide a mechanism for a solar activity-climate correlation if a connection can be found between upper air and surface temperatures.

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Bray, J.R. 1965. Continued

A shortened season for tree growth is probably coincident with an increased period in spring and autumn when glacier budgets at high elevations are positive. Such an increased ice accumulation period may be sufficient to result in a positive yearly ice budget and, eventually, in ice advance at the glacier terminus. An increased likelihood of ice advance during the close of, and following, periods of lower solar activity was demonstrated for all maximum advances and major readvances of glaciers in Alberta, British Columbia, Washington and Oregon.

Regarding glacier advances, the author noted that there may be a lag of up to 18 yr between a period of heavy snow accumulation in an icefield and the conversion of this snow to ice and its maximum distance flow from the icefield. The existence of this lag period may explain the tendency of glacial advance to occur immediately after the close of periods of low sunspot activity. In summarizing the glacier chronological dates, a period of about 15 yr (40% of the length of the subsequent period) was added to the close of each sunspot period and subtracted from the following period. The result of this manipulation clearly showed a tendency for glacial advance to occur during and immediately after low sunspot periods.

The author used a more rigorous selection of glacier chronologies by choosing only dates from direct observation and from information on mature trees that grew immediately outside the glaciated area; from this analysis it was noted that more than three-fourths of the glacial advances occurred during 1707-1715, 1832-1847 and 1893-1914, during the close of, and immediately following, the three periods of lowest sunspot activity.

1. BRAY, J. Roger

2. 1966

3. Similarity of tree growth in northern Scandinavia, polar Urals and the Canadian Rockies.

4. Journal of Glaciology 6:321-322

5. a. Canada, Sweden, U.S.S.R.; Index map NN-11; British Columbia

   b. Larch, Spruce

   c. Climatic change (dendrochronology, proxy data)

6. The author observed that growth patterns for coniferous trees in northern Scandinavia and for Larix sibirica in the polar Urals over the past 250 years are remarkedly similar to the growth of Picea engelmanni in the Canadian Rockies over the same period. The Canadian growth patterns are more nearly synonymous with those of the polar Urals than of Scandinavia.

Conditions for forest tree growth in these three regions were most favourable in the mid to late eighteenth century and following the first two decades of the twentieth century. These two intervals are synchronous with the two periods of maximum mean yearly sunspot numbers since exact European observations began in A.D. 1700. Conversely, the periods 1656 to 1723, 1799 to 1833 and, to a lesser degree, 1879 to 1913 were intervals of minimum forest growth and minimum sunspot activity. The most probable explanation for this apparent correlation of tree growth and sunspot activity is summer temperature, which is apparently higher, on average, during periods of maximum mean yearly sunspot activity.

The author's data record the tendency for the minimum sunspot activity periods (1656 to 1723 and 1799 to 1833) to have been periods of snow accumulation with subsequent major glacier advance in coastal mountain ranges and in the Rocky Mountains. Periods of maximum sunspot activity (1756 to 1798 and 1914 to present) were, on average, intervals of glacial retreat or stagnation.

1. BRAY, J.R.

2. 1971

3. Vegetational distribution, tree growth and crop success in relation to recent climatic change.

4. Advances in Ecological Research 7:177-233

5. a. Northern hemisphere

   b. Larch, spruce

   c. Climate/growth (direct relationships), Climatic change (hypotheses, dendrochronology, proxy data), Climatic variation (temporal, temperature), Treeline studies (climate)

6. During the 8th to 12th centuries A.D., mean temperature for 40 to 90° N latitude was the warmest since the thermal maximum around 4000 B.C., and the period A.D. 1550 to 1750 was the coldest since 500 B.C. There was a maximum difference of 1.9° C between the coldest century, the 16th, and the warmest century, the 11th. The magnitude of the difference between these two extreme periods was least in the equatorial regions and greatest at higher latitudes and altitudes. This is evident from mean annual temperature trends which show differences since 1850 between the coolest (1880) and the warmest (1930) decades that range from less than 1° C in the tropics to greater than 3° C at latitudes between 70 and 80° N. The temperature patterns outlined by the author's review are supported by three geophysical indexes, ^{14}C, ^{18}O and solar activity, which are related to temperature.

Lower ^{14}C values are considered an index of higher temperatures. The ^{18}O values are from the Camp Century, Greenland, ice core and are for the ^{18}O content of precipitation, which is mainly determined by temperature, with lower ^{18}O content associated with lower temperature. These data show a warmer interval from A.D. 300 to 1150 with cooler temperatures from 1200 to 1850, a minimum around 1500 to 1750 and a rising trend from 1850 to the present. The temporal pattern for solar activity parallels that for the ^{14}C and ^{18}O and both ^{14}C and ^{18}O variations have been significantly correlated with the solar activity index.

The solar activity index combines sunspot and auroral observations and, by implication with its inverse relationship to glacial advance, has a positive correlation with temperature given a suitable lag period. The solar activity index indicates slightly lower than normal temperatures in the first 2 centuries A.D. and a plateau of generally warmer temperatures to the end of the 12th century with a brief and minor drop in the 7th century. Beginning in the 13th century, the solar activity data indicate there were generally lower temperatures until the mid 19th century with possible brief reversion to higher temperatures in the late 14th, mid 15th and mid to late 18th centuries, and then a rise in temperature to present, especially after 1915.

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By combining historical accounts with information from the three indicators of temperature changes, the following summary was constructed. Except for the substantially reduced temperatures which began after 1200, reached a minimum in the late 1600's, and then increased to the present, there have been fairly uniform temperatures over the past 2 millennia. For the first 3 or 4 centuries A.D., temperatures were probably similar to the 1930's. There was then a period of general stability with a slight depression around 600 to 700 which culminated in a period of greater warmth than the present around 900 to 1200, often referred to as the Little Climatic Optimum. Temperatures then started a fluctuating decline which culminated around 1650 to 1700 with notable lows in the 1430's, 1560's, 1590's and especially the 1690's and early 1700's. During this decline there were reversions to milder temperatures, particularly in the late 1300's, the mid to late 1400's, the early to mid-1500's and briefly in the 1630's and mid-1600's. After the first decade of the 18th century, there was a discernible general upward temperature trend which has continued to the present with notable periods of warmth in the 1730's, around 1780, the 1830's, the 1870's and the 1930's. There were reversions to cooler temperatures in the 1740's, around 1790, early 1800's around 1850, the 1890's and around 1910.

Changes in the position of altitudinal timberline, defined as the upper border of straight-boled trees, has been assumed to be a response to climatic change. The relationship between temperature, and especially summer temperature, and timberline is the basis of this assumption, though it is apparent that many other factors may be involved. Rampton (1969) working in the Snag-Klutlan area of southwestern Yukon found from carbon dating that around 1220 BP a spruce forest was killed by deposition of up to 1.5 m of volcanic lapilli. This forest was up to 60 m above the modern timberline. Rampton concluded that this showed that climate during the period prior to the deposition was more favourable for propagation and survival of spruce than at present. He noted that the presence of spruce seedlings or saplings above the modern timberline was not frequent enough to suggest that there had been much reaction to the recent warming trend, which was shown by the measurement of tree rings. Rampton considered that, using a lapse rate of 0.7° C/100 m, the minimum increase in mean daily summer temperature should be 0.4° C for a rise in timberline of 60 m and noted that a calculated rise of 1.1° C between 1728 and 1966 had apparently had no effect on the timberline. On this basis he suggested that the actual amount of warming required to raise the altitudinal timberline may be much more than that suggested by the lapse rate.

Latitudinally, there is evidence of a generally stationary phase or southward movement of the northern forest limit in the 19th century and a strong northward advance in the 20th century, especially after 1920. The forest limit in Finland retreated around 2500 yr ago and has readvanced

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most recently since the 1920's and 1930's. Until the mid-1920's it was generally accepted that the forest limit was stable or retreating. Hustich (1948) attributes the recent advance to the warm summers beginning in the 1920's when conditions for regeneration were very satisfactory. He found a simultaneous increase in radial growth of pine and in crop production.

A southward trend of northern treeline in the U.S.S.R. apparently started around 2,000 yr ago and resulted in a retreat of 2 to 4° in latitude. Published maps show a retreat from 160 to 320 km in the area between the White Sea (Arkhangelsk) and the Urals (Anderma). This retreat was still occurring in the early part of the 20th century, but a reversal occurred about 1920 and the forest has now re-advanced 200 to 700 m/yr and in some areas to a total of more than 50 km. Between the White Sea and the Urals, the re-advance has been from 40 to 190 km. There is now convincing evidence that the forest is advancing into the tundra because there is active reproduction, increasing vitality and vigorous growth of larch (Larix daburica) in the Anadyr and Khatanga basins.

In the North American boreal zone, there is evidence of a pattern of retreat and stagnation of the arctic treeline during the 19th and early 20th centuries. The subsequent reversal of this trend began in different areas at varying times. As recently as 1941, Raup concluded that the treeline was advancing in Alaska, retreating in northwestern Mackenzie, approximately stable in southwestern Mackenzie and apparently retreating in eastern Canada.

There is broad agreement that tree growth close to altitudinal or polar limits is mainly controlled by temperature. This control is exerted during the current season, especially in the early part. Temperature during the warmest part of the day is apparently of greatest importance. There also seems to be some effects upon tree growth by temperature variations of the preceding season.

No study has given any indication of a clear influence of precipitation on growth of trees near their northern limits, though it is evident that drainage is an important control over site quality. At lower elevations and latitudes, the control of temperature declines and precipitation is of increasing importance in regulating tree growth. Slåstad (1953) found that growth at the bottom of a valley in Norway was influenced by rainfall, while on the sides of the valley and up to timberline, temperature was the main factor.

Adamenko (1963) plotted the weighted tree ring index of Schove (1954) for Scandinavia against the growth of larch (Larix sibirica) in the polar Urals and concluded that the results were strikingly similar if there was a 25-yr lag between the data. He concluded that this change in phase was due to a large-scale change in atmospheric circulation and a delay in the

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growth of Scandinavian trees was explained by the delay in the frequency of anticyclonic situations in western Europe compared with eastern Europe. Adamenko found more favourable conditions for tree growth in the 18th century and in the 20th century after the 1920's. These patterns were also noted by Bray (1966), who found that Canadian data were similar to those of the polar Urals with higher growth in the mid to late 18th century, and following the first two decades of the 20th century. A further circumpolar comparison by Haugen (1967) found highly significant correlations for 19 of 23 50-yr intervals between 1650 and the present for his own data on white spruce from interior Alaska and for the polar Urals data of Adamenko, the Schove Scandinavian index and the Hustich data from Labrador. He considered the basis of the similarity in tree growth was summer (June or July) temperatures.

Changes in plant growth and vegetational distribution for which a climatic explanation is possible appear to have been broadly synchronous throughout the world over the past 2 millennia. A similar global climatic synchronism was demonstrated on a statistical basis for glaciation in North America, Eurasia and the Southern Hemisphere over the same interval. The pattern of cooling, following the Little Climatic Optimum from 900 to 1200 A.D., is shown by all of the vegetational distribution and plant growth data, though the European tree altitude distribution changes were evident at a earlier stage than those in North America. Change in arctic treeline, while synchronous for Eurasia and North America, is mainly evident since the 1920's, perhaps because observations in the Arctic were not often recorded until the 19th century, a period of generally lower temperature and forest retreat, thus missing the possibility of observations on a possible northward movement during the warmth of the late 18th century.

Assessment of the relationship of tree growth to climate is hampered by lack of data before A.D. 1350 and by difficulty in correcting for age trend. The period of increasing temperature after the minimum in the 17th century is reflected by all the tree growth data which show a growth increase to near maximum values in the late 18th century, a recession in the 19th century and, in most cases, a recovery in the 20th century, especially after 1930.

The evidence that there are synchronous changes to warming or cooling in various parts of the globe suggests that there is a physical control over climate that operates on a global scale. The most likely explanation of such control would be variation in solar radiation retention or receipt by the earth or variation in solar output. No atmospheric mechanism is known from the pre-industrial age which could have changed the amount of radiation retained by the atmosphere, but there is the possibility that changes in earth surface albedo could have affected retention at ground level. However, it has been suggested that an increase in the mean winter albedo of Europe, which occurred as a result of large-scale

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deforestation, may have been the cause of cooling from about 1200 A.D. It has also been suggested that a similar result may have occurred from the large deforestation in the U.S.A. in the 18th and 19th centuries.

A major factor influencing the receipt of solar radiation at the earth's surface is volcanism. A graph of great volcanic eruptions in Iceland and of polar ice off Iceland at 20-yr intervals from 860 A.D. to the present showed an apparent association between glaciation and volcanism. World temperature departures for the 2 yr preceding and 5 yr following 13 major volcanic eruptions were summarized as follows:

Year relative to major eruption	Mean temperature departure (°C)
-2	+0.07
-1	0.00
0	+0.08
+1	-0.31
+2	-0.27
+3	-0.07
+4	+0.15
+5	+0.28

The influence of volcanism on climate seems to be mainly a short-term one with volcanic eruption causing temperature decline and decrease in plant growth in cooler climates and perhaps regulating the periodicity, though not the occurrence, of glaciation. There is little indication that volcanism causes long term climatic changes.

In summary, the extensive cooling after the 13th century is thought to be the result of lowered solar activity which resulted in a period of decreased temperature. At the close of this period there was a major phase of glaciation in which glacial periodicity was regulated by the effects of an active period of volcanism. An interval of generally increased solar activity following the late 17th century has continued to the present, accompanied by a fluctuating rise in temperature. The period after 1930, in particular, has been characterized by high solar activity and almost no volcanism. The author concluded that there is a certain sensitivity of vegetation to climatic change on the order of centuries and millennia. This sensitivity is in marked contrast to the usual failure to establish vegetation-climate relationships based on yearly or decadal means which has led some scientists to consider climatic change of little significance in interpreting vegetation dynamics. As an awareness grows of the possibilities of using botanical data to assess climatic changes of the recent past it is likely that present techniques will be more widely and accurately applied. When this occurs, it is likely that a more subtle picture will be available of the period of temperature decline which followed the Little Climatic Optimum and of the nature of the recovery that has taken place, especially since the 1930's.

1. BRAY, J.R.

2. 1978

3. Volcanic eruptions and climate during the past 500 years.

4. IN: A.B. Pittock, L.A. Frakes, D. Jenssen, J.A. Peterson, J.W. Zillman, Editors, Climatic change and variability, a southern perspective. Cambridge University Press, New York. p. 256-262

5. a. Northern hemisphere

   b. Nil

   c. Climatic change (hypotheses), Climatic variation (temporal)

6. There are significant tendencies for low temperatures and for poor grain harvests in the high latitude regions of the northern hemisphere to follow volcanic eruptions. The low grain yield dates combined with the low temperature date gave a general temperature pattern for the period from 1500 to 1970 A.D. which was significantly associated with volcanic eruptions with a dust veil index equal to or greater than 1,000. The greater the eruption and the more these eruptions were part of a closely spaced series, the longer lasting and more intense were these low temperature phases. Many of the major glacial advance periods since 1500 A.D. may have been triggered by the shorter ablation periods caused by the cold resulting from large eruptions and especially from a series of large and closely spaced eruptions. This conclusion does not imply that volcanism caused the Little Ice Age, but rather that volcanism may be related to the timing of the Holocene ice advances and may have contributed to the lowered global temperatures that accompanied these phases.

1. BRAY, J.R. and L.A. DUDKIEWICZ

2. 1963

3. The composition, biomass and productivity of two Populus forests.

4. Bulletin of the Torrey Botanical Club 90(5):298-308

5. a. Canada, Minnesota; Index map NL-17, Ontario

   b. Aspen

   c. Biomass (tree, shrub/herb)

6. A study was made of the composition, biomass and organic production of two Populus forests which were both about 40 yr of age, but which differed in manner of origin and in site conditions. One stand was near Dorset, Ontario, and the second stand was in the southeastern portion of Itasca State Park near Park Rapids, Minnesota.

The total dry weight above-ground biomass of the Dorset stand (60 t/ha) was only slightly over one-quarter of the value for the Itasca stand (230 t/ha), although dead stem litter had been removed from the Dorset stand and the undisturbed Dorset value would perhaps have been several metic tons per hectare higher than recorded. Biomass and productivity data for the two stands are summarized below:

	Biomass Dry wt. g/m^2		Productivity Dry wt. g/m^2/yr	
	Dorset	Itasca	Dorset	Itasca
Overstory				
Leaves	155	569	155	382*
Under 1 year branches	-	33	-	33
Over 1 year branches	910**	1,724	24**	42
Dead branches	-	362	-	9
Bole	4,721	18,187	131	443
Understory				
Saplings and seedlings	-	14	-	3
Shrubs and herbs	167***	74	102***	52
Dead stem litter	-	2,054	-	50
Total	5,953	22,817	412	1,014

* Corrected for insect consumption
** These figures are a total for all three classes of branches
*** Including saplings and seedlings of tree species

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In the Itasca stand, 3.5% of the tree leaf canopy had been consumed by herbivores by the end of July. The mean original leaf size was 21.4 cm^2 and the mean consumed area per leaf was 0.75 cm^2.

The higher productivity of the Itasca stand may be partly the result of a greater growth potential for Populus tremuloides compared with P. grandidentata. In the Great Lakes area, both these species are pioneers that appear soon after a fire or other disturbance. The two species often occur together in the same stand, where they are usually of the same age and size. The Itasca stand was nearly 2° N of Dorset and occurred within a vegetation transition area in which Acer saccharum and Tilia americana are rare and near their distribution limit. At Dorset, Acer saccharum and Fagus grandifolia are common on the uplands which indicates the climate of the Dorset area may be more moderate than that of the Itasca area. This suggests that the differences in productivity between two stands are not mainly climatic, but are probably closely related to local conditions of soil moisture and soil fertility. The Dorset stand had been used as a crop field and then abandoned, perhaps because of a depletion of mineral nutrients in the soil. The Itasca stand had not been used for agriculture and it had benefited from the release of nutrients which accompanied the burning of the vegetation before the origin of the present forest. The more mesic soil conditions at Itasca, as shown by the higher silt content and the herb composition, may also be a factor in the greater Itasca productivity.

1. BRAY, J. Roger and Eville GORHAM

2. 1964

3. Litter production in forests of the world.

4. Advances in Ecological Research 2:101-157

5. a. Finland, Norway, Sweden, U.S.S.R.

   b. Birch, larch, Scots pine, Norway spruce

   c. Biomass (tree, shrub/herb)

6. This review of world literature analyses data on forest leaf litter and non-leaf litter, factors influencing litter fall, standing crop of leaves, and leaf litter as an index of net primary production.

The authors' tables of annual litter production contained the following data for species from the boreal forest zone in Eurasia.

Species	Country	Lat. & Long.		Litter-fall (t/ha/yr) Leaves	Other	Total
Pinus sylvestris	Finland	62N	22E	-	-	2.6
Picea abies	Finland	62N	22E	-	-	1.6
Betula	Finland	62N	22E	-	-	1.9
Pinus sylvestris	Finland	61N	25E	1.7	0.6	2.3
Pinus sylvestris	Finland	61N	25E	1.2	0.6	1.8
Pinus sylvestris	Finland	62N	25E	-	-	2.7
Picea abies	Finland	61N	25E	1.9	1.0	2.8
Picea abies	Finland	61N	25E	1.9	0.5	2.4
Picea abies	Finland	62N	24E	1.7	0.4	2.2
Betula	Finland	61N	25E	1.3	0.5	1.8
Betula	Finland	61N	25E	-	-	1.5
Larix sibirica	Norway	60N	11E	-	-	2.8
Larix sibirica	Norway	61N	11E	-	-	2.8
Larix sibirica	Norway	62N	11E	-	-	1.2
Larix decidua	Norway	60N	12E	-	-	2.1
Larix leptolepis	Norway	60N	11E	-	-	3.4
Picea abies	Norway	60N	12E	-	-	2.0
Picea abies	Norway	60N	11E	-	-	3.2
Picea abies	Norway	61N	11E	-	-	2.0
Picea abies	Norway	59N	10E	-	-	4.5
Pinus sylvestris	Norway	62N	11E	-	-	2.6
Picea abies	Norway	60N	11E	2.5	0.6	3.1
Picea abies	Norway	61N	11E	1.5	0.3	1.9
Betula	Norway	61N	11E	1.3	0.6	1.9
Picea abies	Norway	62N	10E	0.9	0.6	1.5
Picea sylvestris	Norway	62N	10E	0.5	0.3	0.8
Betula	Norway	62N	10E	0.6	0.2	0.8

Continued ...

Species	Country	Lat. & Long.		Litter-fall (t/ha/yr) Leaves	Other	Total
Betula pubescens	Sweden	60N	15E	1.7	-	-
Populus tremula	Sweden	59N	18E	1.9	-	-
Betula pubescens	Sweden	59N	18E	1.6	0.1	1.7
Picea abies	Sweden	59N	18E	3.1	-	-
Picea abies	U.S.S.R.	57N	31E	-	-	4.5
Pinus sylvestris	U.S.S.R.	56N	38E	-	-	3.0
Pinus sylvestris	U.S.S.R.	56N	38E	-	-	3.6
Pinus sylvestris	U.S.S.R.	56N	38E	-	-	4.2
Picea abies	U.S.S.R.	56N	38E	-	-	6.2
Picea abies	U.S.S.R.	56N	38E	-	-	6.9
Pinus sylvestris	U.S.S.R.	67N	37E	-	-	0.6
Pinus sylvestris	U.S.S.R.	67N	37E	-	-	1.0

Because of their evergreen nature, gymnosperms might be expected to be more productive than deciduous angiosperm trees, although this factor may be countered to some extent by the tendency for angiosperm forests to occupy more fertile sites. When a wide range of sites is considered gymnosperms yield about one-sixth more litter annually than angiosperms, the difference amounting to 0.5 t/ha. A comparison of litter production by evergreen and deciduous trees in the northern hemisphere resulted in the following estimates.

	Evergreen gymnosperms (t/ha/yr)	Deciduous angiosperms (t/ha/yr)
Total litter	3.7	3.2
Leaf litter	2.6	2.4
Other litter	0.7	0.7

The major role of temperature in controlling litter production is illustrated when total annual litter-fall is plotted versus latitude. The relationship is inverse and linear, with a maximum level of over 11 t/ha at the equator declining steadily to a little less than 1 t/ha at latitude 65° N in Europe, where forest grades into tundra.

Although leaf litter represents an amount somewhat less than leaf production, owing to intrinsic and extrinsic weight losses prior to and probably also following abscission, the authors considered leaf litter data useful as a guide to minimum levels of net primary production. Relative litter production by climatic zones was summarized by the authors, together with various indexes of net primary production as shown in the following table, with arctic-alpine values being taken as unity in the first three columns, and cold temperate values taken as unity in the last three columns.

Continued ...

Bray, J.R. and E. Gorham. 1964. Continued

	Total litter	Leaf litter	Bole prod.	Total prod.	Total broad-leaved tree prod.	Total needle-leaved tree prod.
Arctic-alpine	1.0	1.0	1.0	-	-	-
Cold temperate	3.5	3.6	2.7	1.0	1.0	1.0
Warm temperate	5.5	5.1	5.1	-	-	-
Equatorial	10.9	9.7	7.0	2.3	3.0	2.4

In general, equatorial forest is two to three times as productive as cold temperate forest; warm temperate forest productivity is nearer to cold temperate than to equatorial forest productivity, and arctic-alpine forest is less than half as productive as cold temperate forest.

The apparent lower efficiency of tropical tree leaves in producing non-leaf material probably reflects a high rate of respiration (relative to rate of photosynthesis) under higher tropical temperature. The higher efficiency of temperate gymnosperm needles as compared with angiosperm leaves in producing non-leaf material may be a result of their much longer period (more than two years) of contribution to net production. The authors suggest that leaf litter cannot be employed directly as an index of net forest production, since evergreen gymnosperm leaves produce annually over 40% more non-leaf material than do deciduous angiosperm leaves, and over 60% more than equatorial forest leaves. The use of leaf litter values as production indices would therefore greatly overestimate equatorial forest production and underestimate production by evergreen gymnosperms. The cool temperate gymnosperms are about 25% more productive than the angiosperms (13.2 t/ha as against 10.5 t/ha). The evergreen nature of gymnosperm trees which allows photosynthesis whenever temperatures are suitable, and the great weight of canopy carried are presumably responsible for comparatively high levels of production in gymnosperms. In a general comparison over wide areas, however, the tendency of angiosperms to occur on better soils than gymnosperms may lessen the differences in production brought about by the greater canopy weight and longer leaf duration of gymnosperms.

1. BRAY, J.R. and G.J. STRUIK

2. 1963

3. Forest growth and glacial chronology in eastern British Columbia, and their relation to recent climatic trends.

4. Canadian Journal of Botany 41:1245-1271

5. a. Canada; Index map NH-11; British Columbia

   b. Spruce

   c. Climatic change (hypotheses, dendrochronology, proxy data)

6. Recent activity of Yoho Glacier was determined by botanical and geological dating techniques and from published accounts. Tree growth in four forests adjacent to the end moraine was measured by increment borings of 200 Engelmann spruce. A positive correlation between forest growth and growing season temperature was expected since the Yoho forests occur at high elevations where growth patterns were expected by the authors to be similar to those for northern limits of the boreal forest in which growth is primarily related to temperature. It is improbable that the growth of the Yoho forests, which receive snow meltwater throughout almost the entire growing season, is primarily related to precipitation. The existence of a negative correlation between the Yoho growth data and Willett's world precipitation regime is probably the result of the negative correlation between Willett's temperature and precipitation regimes, in which increasing precipitation is accompanied by decreasing temperature.

A summary of climate, forest growth, and glacial activity by 50 yr intervals for data from 1580 to 1950 is shown in the table below. Also included in the table are data on the number of weeks of ice per year in the ocean off Iceland.

	Indicator of climatic patterns*					
	1	2	3	4	5	6
1901-1950	.92	0	9	+	-	57
1851-1900	.82	4	44	-	+	44
1801-1850	.78	14	37	-	+	41
1751-1800	.84	2	32	+	-	52
1701-1750	.80	10	18	-	+	Low
1651-1700	.84	1	23	-	+	Low
1601-1650	.87	2	23	+	-	Medium
1581-1600	.88	0	3	+	-	High

* 1. Relative forest growth, Yoho; 2. Number of glacial advances in Alberta, British Columbia, Washington and Oregon; 3. Ice off Iceland, number of weeks per year; 4. Relative world temperature; 5. Relative world precipitation; 6. Mean yearly sunspot number

Continued ...

Bray, J.R. and G.J. Struik. 1963. Continued

In general, periods of lower solar activity, as in 1650 to 1750 or 1800 or 1850, were also periods of lower Yoho tree growth, lower world temperature, and higher world precipitation. These periods were accompanied or closely followed by glacial advances in western North America and by an increase in the ice off Iceland. Periods of higher solar activity, as from 1750 to 1800 or 1900 to 1950, were characterized by greater tree growth, higher temperature and lower precipitation.

There is a possibility that mean solar activity, since accurate sunspot observation began in 1749, has been relatively moderate to low, and probably less than activity in the 9th to 14th centuries, when the number of sunspot plus aurorae years was over twice that in the 17th to 19th centuries. It is conceivable that, in some future solar cycle, a higher level of solar activity will occur than in the recent maximum cycle of 1947 to 1957. There is evidence for phases in the sunspot activity cycle of around 35 to 45 yr and of around 70 to 90 yr, as illustrated by the low activity intervals of 1645 to 1715 and 1798 to 1833. A phase of relatively high sunspot activity apparently began in 1913. If this phase had been around 40 yr in length, it should have ended around 1950, to be followed by an interval of lower solar activity. Instead, the decade 1951 to 1960 had the highest mean sunspot number on record, and 1957 had the highest maximum. This suggests the present relatively high level of solar activity may last over an 80 to 90 yr phase, or until nearly the end of the 20th century. If this occurs, the general warming trend in world climate should continue, or at least not reverse, and the tendency for glacial retreat or stagnation should last to at least the end of the present century.

1. **BRINGMARK, Lage**

2. 1977

3. A bioelement budget of an old scots pine forest in central Sweden.

4. Silva Fennica 11(3):201-257

5. a. Sweden

   b. Scots pine

   c. Biomass (tree, shrub/herb, moss/lichen)

6. This paper describes the nutrient budget of a Scots pine forest in central Sweden, including data on biomass components of the forest stand.

The investigated stand was situated near Jadraas, Sweden (60 00 N, 16 00 E), where average annual precipitation is 607 mm, of which 326 mm falls during the growing season. The forest was an old Scots pine stand with 393 stems/ha and stand age of 120 to 150 yr. The understory consisted mainly of **Calluna vulgaris, Vaccinium vitis-idaea, Pleurozium schreberi** and **Cladonia** sp.

The dry weights of the biomass components of the ecosystem were as follows:

Biomass component	Dry weight (g/m^2)
Scots pine biomass	
current needles	126.2
current shoots	25.7
older needles	267.5
older shoots	56.0
branches	810.5
stemwood	4,519.4
stembark	304.9
stump and big roots	1,424.2
roots 5 to 10 mm	289.6
roots less than 10 mm	295.0
Calluna vulgaris biomass	
capsules	1.2
current shoots	38.7
shoots 1-yr old	37.2
shoots older than 1 yr	55.8
roots greater than 2 mm	127.3
roots less than 2 mm	57.1

Continued ...

Biomass component	Dry weight (g/m^2)
Vaccinium vitis-idaea biomass	
current shoots	3.1
shoots 1 and 2 yr old	42.0
older stems	19.1
rhizomes	143.3
Bottom layer	
mosses	128.3
lichens	123.3
Dead standing biomass	
tree branches	57.2
Calluna vulgaris	7.5
Vaccinium vitis-idaea	1.2
Biomass in soil	
total surface litter	479.0
total root litter	216.0
humus layer excluding biomass	1,990.0

The increment of some biomass fractions and litter fall were given as follows:

Biomass fractions	Dry weight ($g/m^2/yr$)
Increments	
branches and shoots	43.4
stemwood	106.1
Litter fall	
needles	92.9
cones	2.5
twigs	10.6
other litter	29.2

The author concluded that a very large part of the annual uptake is used for fine root production. However, the turnover of fine roots is very fast and the nutrients are rapidly returned to the soil. This bioelement turnover could be regarded as a very local circulation in the soil, which might be overlooked in a large-scale ecosystem budget.

The ratios between the uptakes into different plant species show that the dwarf shrubs are taking a large share of especially N, P and S. The uptake into mosses, which has been set equal to moss litter production, is rather large for N and P. The moss carpet is drawing its nutrients

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almost entirely from rain water and is not competing with the trees below ground. The elements in the throughfall are withheld for some time on their way into the soil.

The turnover times for the below-ground parts of pine and dwarf shrubs are all about one year. If pine roots less than 1 cm had been considered separately the turnover would have been even faster.

1. BRINKMANN, W.A.R.

2. 1979

3. Growing season length as an indicator of climatic variations?

4. Climatic Change 2:127-138

5. a. Wisconsin

   b. Nil

   c. Climatic variation (temporal, temperature), Growing season (frosts, length)

6. Concern about the impact on the world food supply as a result of a recent downward trend in average surface temperature in the northern hemisphere has increased interest in possible changes in length of the growing season. There is also concern over possible increases in weather variability and its impact on food supply. Increased variability has been proposed to be linked to hemispheric cooling and associated amplification of the circumpolar wave pattern, which would cause greater extremes in weather as indicated by the works of Bryson and Lamb. Most studies of climatic variabi'ity have been concerned with variance in the monthly, seasonal and annual scale, but it is also possible that the variability of daily temperatures is changing, which could influence the length of the growing season. An increase in the magnitude and/or frequency of very low daily minimum temperatures, for instance, could result in a later onset or an earlier end of the 'freeze free' season. The growing season is considered by some to be a simple and yet significant indicator of the impact of hemispheric temperature variations at the local level. Yet, the effect of the use of different definitions of the growing season has never been determined.

The definiton of the growing season represents another problem. The growing season has been defined as the number of days in a year that a plant can grow. A common measure of the growing season has been the number of days between the last killing frost in spring and the first killing frost in fall. A 'killing frost' is defined non-numerically as the freezing condition th t kills cultivated vegetation in the vicinity of an observing station. This definition has many faults. The killing temperature varies widely with plant species, stage of plant development, duration of freezing and rate of freezing. The National Climatic Centre in the United States now reports the last and first dates of certain minimum temperatures, such as 0° C, -2.2° C, and -4.4° C. The intervals between the last and first occurrences of these minimum temperatures have been used as indices of the growing season. However, plant growth is often greatly retarded at temperatures near, but above, freezing. Some workers have therefore used the interval between the last and first occurrence of a minimum temperature of 5.5° C as an index of the growing season. Although a number of working definitions of the growing season

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have been used, they have never been compared. The purpose of the author's study was to show that differently defined growing seasons can vary in their long-term trends and that the length of the growing season is therefore not the simple climatic indicator it has been assumed to be.

In this study, time series of the length of differently defined growing seasons at four Wisconsin stations were compared. The results showed that their lengths have fluctuated in a variety of patterns over the past 80 yr. Two growing seasons which showed a significant trend did not agree on its direction. The reason for this disparity is that trends in maximum and minimum temperatures are not necessarily of the same sign at different times of the year.

The author reasoned that long-term fluctuations in length of the growing season, no matter how it is defined, must be related to temperature fluctuations. Differences between differently defined seasons must therefore be due to differences in the maximum and minimum temperature trends for different months. This study showed that long-term trends in the length of the growing season are related to trends in the monthly maximum or minimum temperatures and, to some degree, to trends in the standard deviations of daily te perature of the month in which the onset and end of the season occurs. Since temperature trends are not necessarily the same for different months, and since long-term fluctuations in maximum and minimum temperatures are not necessarily parallel, differently defined growing seasons can and do show different long-term trends. The author indicated that it would be desirable to do similar studies in a variety of climatic regimes in different parts of the world.

1. BRINKMAN, W.A.R. and R.G. BARRY

2. 1972

3. Palaeoclimatological aspects of the synoptic climatology of Keewatin, Northwest Territories, Canada.

4. Palaeogeography, Palaeoclimatology, Palaeoecology 11:79-91

5. a. Canada; Index maps NP-13/14, NO-19, NO-20, NN-19, NN-20, NN-21; Keewatin; Labrador; B.13a, B.27, B.32

   b. Nil

   c. Climate (air masses, precipitation, temperature), Climatic variation (regional, temporal, temperature, precipitation)

6. The aims of this study were twofold. First, to investigate present-day circulation patterns which give rise to conditions favouring glacierization over Keewatin. Second, to examine the related question of the effect of displacements of the mean troposphere trough in the westerlies from its normal position over Baffin Island and Labrador-Ungava. Westward displacements were considered in this paper since eastward shifts tend to place Keewatin and Labrador-Ungava both on the western limb of the trough under a general northwesterly flow.

Days of heavy winter precipitation in Keewatin are associated with dry conditions over Labrador-Ungava and vice versa. This results from depressions being steered across one or the other area. An upper trough over eastern North America is responsible for depressions crossing Labrador-Ungava while one over western North America, which is usually associated with another off the east coast, gives rise to a track across Keewatin.

Cool summer months over the two districts are generally wet in Labrador-Ungava but dry in Keewatin. Analysis of the daily circulation characteristics shows that cold spells tend to occur simultaneously in both areas; this is especially so when an outbreak of arctic air behind a cold front moving south of Labrador-Ungava gives a spell of cold days. The deep 700 mbar trough over eastern Hudson Bay during these months explains the high precipitation over Labrador-Ungava while Keewatin remains under northerly flow. The cloud cover over Keewatin nevertheless averages over 70% under these conditions thereby further suppressing temperatures.

In summer, a mean 700 mbar trough displaced to the west - a pattern very similar to that found for cool summer months - is associated with increased precipitation in Labrador-Ungava and somewhat reduced amounts in Keewatin. Under such circumstances, temperatures over both areas, as well as over much of Canada, are slightly below average, reflecting the negative 700 mbar height anomalies. When the trough is deeper than

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normal over Labrador-Ungava, temperatures are near normal over Keewatin with diminished precipitation; at the same time, precipitation is heavy over most of Labrador-Ungava with slightly below normal temperatures.

The authors concluded that cool summer spells in the present era can affect both areas simultaneously, but the weather is generally dry in Keewatin and wet in Labrador-Ungava. These conditions are associated with a deep 700 mbar trough over eastern Hudson Bay. The results suggest that vegetation changes that are determined primarily by summer precipitation should not be expected to be in phase in Keewatin and northwest Labrador-Ungava. However, the temperature differences between these areas with respect to either trough pattern are probably too slight to be of any consequence. Since the advances and retreats of the boreal forest reported by Nichols (1970) are most likely to be determined by temperature there is, therefore, nothing in the present work to contradict the palynological arguments for parallel changes in Keewatin and northern Ungava.

1. BROWN, R.J.E.

2. 1970

3. Permafrost as an ecological factor in the subarctic.

4. IN: Ecology of the Subarctic Regions, Proceedings of the Helsinki Symposium. UNESCO, Paris. p. 129-140

5. a. Northern hemisphere

   b. Nil

   c. Climate (temperature), Treeline studies (climate)

6. Throughout the northern hemisphere, the northern limit of discontinuous permafrost generally lies south of the treeline. Exceptions of this occur in North America east of Hudson Bay, and in Eurasia from the Atlantic Ocean to the Yenisey River. The northern limit of discontinuous permafrost and the treeline are closer together in the western hemisphere than in the eastern hemisphere and are approximately parallel to each other. In Canada, the treeline is approximately 800 km south of the continuous permafrost zone east of Hudson Bay and about the same distance north of it in western Canada. In Alaska, the treeline lies about 500 km north of the discontinuous permafrost zone.

Continuous permafrost has not been reported in northern Scandinavia and the treeline actually lies close to the southern limit of discontinuous permafrost. In the Soviet Union, the northern limit of discontinuous permafrost extends inland from the arctic coast at Novaya Zemlya, extends southeastwards across the Ob Gulf at 70° N and reaches 60° N east of Yakutsk, more than 1,000 km south of the treeline. Further east it trends to the northeast and reaches the Bering Sea at Anadyr. In contrast to the great southward penetration of the northern limit of discontinuous permafrost in Siberia, the treeline extends eastwards at about 70° N to the far east where it dips southwards to Kamchatka Peninsula.

1. BRYSON, Reid A.

2. 1966

3. Air masses, streamlines, and the boreal forest.

4. Geographical Bulletin 8(3):228-269

5. a. Canada

   b. Nil

   c. Climate (air masses), Climatic variation (regional), Treeline studies (climate)

6. The author questioned whether it was only the temperature climate that caused the distinctive biotic zones of the north and the research described in this paper was directed to the question of whether there was a natural regionalization of climatic complexes that results ultimately in biotic regions. For many years meteorologists have recognized the existence of naturally occurring atmospheric complexes, generally referred to under the concept of air masses. Arctic air masses, for example, have a certain temperature range in each place and season, and characteristic moisture, turbidity and structure as well. It is the distinctive combination of these elements into a recognizable complex that is at the heart of air mass analysis. The natural, more or less sharp, boundaries between these complexes are known as fronts or frontal zones. If it can be shown that these fronts have distinguishable mean locations, which change with the seasons to create homogeneous regions that differ from each other in air mass regimen, then there can be considered to exist a discontinuous pattern of climatic complexes - independent of the biological data - which can be compared with the biotic distributions.

Field observations provided the original stimulus for the author's meteorological analyses. In the field it had been observed that in midsummer the northern forest border is frequently the location of more disturbed weather than the region either to the north or to the south. In-flight observations of wind changes across this disturbed area strongly suggested the frequent presence of a front near the forest border. Maximum cloud development over the boreal forest to the south was noticed on many days by ground observation just north of the forest border at Ennadai Aeradio Station (61 08 N, 100 51 W).

That fronts and wave cyclones are more common in the general vicinity of the treeline than over either the tundra or boreal forest proper is rather easy to demonstrate through the examination of synoptic charts, though the wide spacing of weather stations makes their precise location difficult. In turn, this implies that the dominance of a particular air mass over the tundra and a different air mass over the boreal forest may help explain causal relationships between climate and biotic communities in the north.

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Bryson, R.A. 1966. Continued

The analyses showed that the area occupied more than half the time by arctic air in July, determined by trajectory, lies north of the treeline in central Canada, and that the area occupied by pacific air on more than half the July days lies south of this biotic boundary. This boundary should then be the modal position of the front that normally separates arctic and pacific air, or approximately the modal track of wave cyclones that move along that front. The agreement in position of the treeline, the storm track, the air mass boundary derived from trajectories, and the air mass boundary derived from the partial collectives of daily maximum temperatures is amazingly good. The author concluded that the northern forest border is also the modal July position of the arctic front in central Canada.

The 50% isopleth for arctic air passes between Reliance, N.W.T. and Artillery Lake, which lies northeast of the eastern end of Great Slave Lake, N.W.T. The forest border is clearly defined in this region and crosses Artillery Lake about 32 km from the position of the 50% isopleth. This same isopleth passes about 32 km south of Ennadai Lake, within 8 to 16 km of the true position of the forest border as seen in the field. The isopleth cannot mirror the detailed irregularities of treeline but it does parallel the forest border very well from Aklavik to the Atlantic Ocean. East of Hudson Bay, four air masses are present and the modal position is indefinite, as is the forest border, on the scale at which the air masses were mapped for this paper.

The southern edge of the boreal forest also follows quite well the 50% isopleth at the northern edge of the wedge of mild pacific air that crosses the Rockies in southern Alberta, Montana and Wyoming. However, this reflects only a change in dominance of mild pacific air versus a cooler variety of pacific air. This seems to be physically too insignificant to be causally related to the boundary between prairie and spruce forest.

The region occupied by the continental polar and arctic airstreams all winter and spring (November to May) but by pacific and tropical air in summer extends from the Rockies to the Atlantic and quite closely matches the distribution of boreal forest. The boreal forest climate is thus defined, and the forest itself lies between the summer and winter positions of the arctic front. An exception is to be found along the eastern edge of the Canadian Rockies where increased elevation causes the forest limit to extend a few degrees southward beyond the winter position of the arctic front, but such topographically-produced anomalies are to be expected. The author also noted that the arctic front seems to be topographically anchored all year at the northern end of the Cordillera near Aklavik, but swings north and south with the seasons in the continental interior where the terrain is relatively flat.

1. BRYSON, Reid A.

2. 1974

3. A perspective on climatic change.

4. Science 184(4138):753-760

5. a. Northern hemisphere

   b. Nil

   c. Climatic change (hypotheses, proxy data), Climatic variation (temporal, temperature)

6. Up to the time of this review, little attention had been given to questions such as: (1) How large must a climatic change be to be important? (2) How fast can the climate change? (3) What are the causal parameters, and why do they change? (4) How sensitive is the climate to small changes in the causal parameters? This article provides a perspective on these questions.

Bergthorsson has reconstructed the decadal mean annual temperature for Iceland over the past 1,000 yr from the historic records of the duration and extent of sea ice on its shores. By calibrating the ice record against the observed climatic data for the past century and a half, he was able to derive a regression equation that makes possible a rather credible decadal temperature plot for the past millenium. This record puts the climatic "normal" period 1931 to 1960 into perspective. The normal period is normal only by definition; there appears to be nothing like it in the past 1,000 yr.

In this 1,000-yr period, how important are the mean temperature variations when the whole range is less than 2° C? The author's analysis shows that a decrease of 1° C in the mean annual temperature of Akureyri, Iceland, would reduce the length of the growing season by about 2 weeks, but would reduce the number of growing degree-days by 27%. A reduction of mean annual temperature by 2.4° C would reduce the number of growing degree days by 54% and the growing season by 40 days (25%). In the late 1950's, hay yields in Iceland averaged 4.33 t/ha with 2.83 kg of nitrogen fertilizer/ha and a mean warm half-year temperature of 7.65° C. In 1966 and 1967, the yields averaged only 3.22 t/ha with 4.83 kg of fertilizer, but with a mean temperature of 6.83° C. The climatic reduction of yield overshadowed the expected technological increase.

There is another way in which small climatic changes are important, and this is related to the physiology of trees and probably most perennials. During one growing season a tree normally stores photosynthates in excess of that year's growth needs. This provides a reserve which is drawn on the following year and makes it possible for the tree to survive a single severe year. Pine trees also retain their needles for a number of years.

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These integrative mechanisms mean that the variance spectrum of tree response to climate should show suppressed response to high-frequency climatic variations. Thus, trees do not necessarily record large seasonal anomalies but they do integrate the effect of small systematic changes into the biomass of the forest. It is not realistic to say that, because trees survive the large interannual variations, climatic mean changes are unimportant.

Since the climate is primarily determined by processes near the earth's surface, the solar energy arriving at the top of the atmosphere is really not as important as that reaching the lower atmosphere. If the physical properties of the atmosphere and the earth were invariant, then about the only cause of climatic variation would be variations in the input from the sun at the top of the atmosphere. However, the transmittance of the atmosphere varies with time, and this variation modulates the receipt of solar energy in the lower atmosphere and at the surface. Historically, by far the greatest influence on atmospheric transmittance has been volcanic activity. Volcanic activity is variable in the right frequency range to match climatic change, the magnitude of the injections of volcanic dust is right, and significant changes of atmospheric transmittance have been measured following eruptions. Work by the author and by others has shown that in the past century a major control of the mean temperature in the northern hemisphere has been volcanic dust augmented by a human contribution.

A particular feature of volcanic activity is that it is sporadic and occurs in pulses, although the frequency and intensity of these pulses vary greatly. If the colder periods of recent earth history have been due to pulsed volcanic injections that reduce atmospheric transmittance, then these colder periods should have more temperature variance than the warm periods of volcanic quiescence. This is evident in data presented by the author.

Changes of atmospheric transmittance as a result of particulate input by humans was estimated by the author to involve (40 to 60) x 10^6 t from smoke from slash-and-burn agriculture and (100 to 250) x 10^6 t from deflation of soil disturbed by agriculture and construction. An important question is how much of the man-generated particulate material remains in the atmosphere at any given time. The particulate loading of the atmosphere due to human activities is estimated at (8 to 24) x 10^6 t, that is an amount comparable to that produced by moderate volcanic activity. An increase of 2 x 10^6 t in atmospheric loading is capable of reducing world mean temperatures by 0.4° C. Thus, both men and volcanoes appear adequate to account for the hemispheric cooling since 1940.

It is significant for the boreal forest region that most of the recent increase of turbidity has been at middle to high latitudes. This, plus

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the greater path length of sunlight through the atmosphere at higher latitudes, should have produced selective cooling of these latitudes and that is what has been observed.

The concentration of carbon dioxide in the atmosphere is currently about 320 ppm and is increasing about 1 ppm annually. The evidence suggests that this rate will also increase, and is greater now than a decade ago, and the estimated effect is that global mean surface temperature will rise roughly 0.01° C per ppm carbon dioxide increase. In the last century the carbon dioxide content of the atmosphere changed from about 292 to about 320 ppm. If this were the only cause of climatic change, the mean global surface temperature should have risen steadily and smoothly, at an increasing rate, by about 0.25° C. It has not, and in fact has decreased by about that amount since 1940. There clearly are other factors of greater magnitude that dominate climatic changes in terms of mean global surface temperature.

In this review, the author assumed that variations of the gross energy flow, extrinsic to the atmosphere, are adequate to explain climatic variations without seeking some "trigger" mechanism of small size, such as a burst of solar particles which modifies the high atmosphere. This does not imply that there is no short-term atmospheric effect, but that there is simply no climatic effect of significance compared to those that relate to the all-important solar energy that drives the atmosphere. Also implicit is the assumption that climate is thermodynamically forced and that the overall hydrodynamic pattern of waves, eddies, momentum fluxes, and the like is an internal response to this forcing.

This review showed that numerically small changes in climatic variables may produce significant environmental changes and that rather small changes in the extrinsic control variables are adequate to explain these responses. A significant feature of recent paleoclimatic research is that significant climatic pattern changes are surprisingly small; explanation of past environments does not require drastic modification of the general circulation.

The data presented show that climate can change very rapidly. While some causal parameters, such as earth-sun geometry, change slowly, others, such as volcano-induced turbidity, may change rapidly and sporadically. Apparently the only controls of the speed of climatic changes are the time constant of the active layer at the surface of the earth and the time constant of glaciers. Ice age climates may end, and probably start, in a century or two, although glacial and oceanic response and a new equilibrium may take millennia. Holocene climatic changes, smaller in magnitude, may be accomplished in decades.

1. BRYSON, Reid A. and Brian M. GOODMAN

2. 1980

3. Volcanic activity and climatic change.

4. Science 207:1041-1044

5. a. Northern hemisphere

   b. Mil

   c. Climatic change (hypotheses, proxy data)

6. The more successful simulations of the course of hemispheric or zonal temperatures over the past century have been based on the assumption that the transparency of cloudless atmosphere has varied in response to variations of volcanically produced turbidity. In part, these models help distinguish between variations of direct-beam solar radiation observed at the surface and variations produced by volcanic debris changing the atmospheric transparency. The authors stressed that it will be necessary to estimate future levels of volcanic activity if the objective is to estimate climatic conditions for the coming few decades or for a century.

If the decline of atmospheric transparency since around 1945 is to be ascribed to increased volcanic activity, one should be able to find data that support the supposition. The authors analyzed the listing of about 6,000 historically recorded volcanic eruptions in the files of the Centre for Climatic Research at the University of Wisconsin, Madison. This is approximately ten times the number of eruptions documented in the Lamb chronology. Far more eruptions of all magnitudes were recorded during the early years of this century and in the last decade than during the period 1925 to 1955. Indeed, the course of volcanic activity in this century is the inverse of the well-known course of hemispheric mean temperature. From 1945 to 1970, the annual eruption numbers roughly doubled from 16 to 18/yr to 37 to 40/yr. During the same interval, the aerosol optical depth also roughly doubled. These data agree with reports of a doubling in the amount of nonorganic impurities deposited on the Greenland Ice Sheet between times of low and high volcanic activity, based on ice core analysis for the past 300 yr.

There is a hint of a roughly 3,000 yr periodicity, especially in the last 20,000 yr, in the level of northern hemisphere volcanic activity. However, much more investigation would be necessary to establish its reality.

1. BRYSON, Reid A., William N. IRVING and James A. LARSEN

2. 1965

3. Radiocarbon and soil evidence of former forest in the southern Canadian tundra.

4. Science 147:46-48

5. a. Canada; Index map NP-13/14; Keewatin; B.32

   b. Black spruce

   c. Climatic change (proxy data), Treeline studies (climate)

6. After the draining of great glacier-dammed lakes in southwestern Keewatin not later than 3500 B.C., forest encroached northward to at least about 63 00 N and remained until about 1500 B.C., developing a typical podzol soil. About 1500 B.C. the forest failed to regenerate after fires, and the treeline retreated south of Ennadai Lake. By A.D. 1000 the forest had again advanced to at least 61 30 N or 62 00 N. Fires of that time were not followed by forest regeneration north of the present treeline. Thus, the treeline twice advanced north of its present position and was farther south than at present during an intervening period between 1500 B.C. and A.D. 1000. Because the treeline presently coincides with the position of the Arctic front, the authors infer that these periods of northward forest extension were periods with a more northerly frontal position.

The clumps of black spruce that now occur in the area north of the present treeline and extending to Dubawnt Lake appear to represent relics that survived the fires and now occupy rare favorable sites. The evidence presented by the authors shows that a wide strip at the southern edge of the tundra was once forested long enough to develop podzol soils, and that the treeline has not been moving steadily northward during all of postglacial time.

The known history of human occupancy of this area also reflects this sequence of biotic and climatic change. Late Paleo-Indian artifacts, like those of buffalo hunters in the plains and Great Lakes regions 7000 to 9000 yr ago, are found on sites exposed after the draining of the proglacial lakes in the Dubawnt and Kazan river systems. These sites were forested until 3500 yr ago. The first arrival of Arctic culture in the region (pre-Dorset stage of the Arctic small-tool tradition) probably took place 3000 to 4000 yr ago, with the onset of more severe climate and the retreat of the forest border. The recent Caribou Eskimo came after the forest retreat of 900 yr ago.

1. **BRYSON, Reid A. and Wayne M. Wendland**

2. 1967

3. Tentative climatic patterns for some late glacial and post-glacial episodes in central North America.

4. IN: W.J. Mayer-Oakes, Editor, Life, Land and Water, Proceedings of the 1966 Conference on Environmental Studies of the Glacial Lake Agassiz Region, University of Manitoba Press, Winnipeg. p. 271-298

5. a. Northern hemisphere

   b. Nil

   c. Climate (air masses), Climatic change (hypotheses, proxy data)

6. The purpose of this paper was to present a few tentative reconstructions of past airmass regimes. The authors attempted partial reconstruction for three times: the late glacial period of about 13,000 to 10,000 yr ago, the period around 9,000 to 8,000 yr ago and the period around 5,000 to 3,500 yr ago plus some comments on the smaller fluctuations since that time. The authors proposed the following climatic episodes in the last 2500 yr:

Episode	Rough date
Recent	1850 A.D. - 1960 A.D.
Neo-boreal	1550 A.D. - 1850 A.D.
Pacific II	1450 A.D. - 1550 A.D.
Pacific I	1200 A.D. - 1450 A.D.
Neo-Atlantic	900 A.D. - 1200 A.D.
Scandic	400 A.D. - 900 A.D.
Sub-Atlantic	550 B.C. - 400 A.D.

An example of the information available in this article is the following description of the 'Neo-boreal' climatic episode. The Pacific episode (1200 to 1550 A.D.) of increased westerlies was followed by an expansion of the circumpolar vortex and a return to patterns more like the Sub-Atlantic. A far south jet stream in winter associated with blocking highs over northwest Europe and a reduced summertime penetration of tropical air northward across the United States and into Canada is indicated by historical data. Summers were cool in the Neo-boreal (1550 to 1850 A.D.) and autumns cold (about 4° F below normal) in the eastern United States. Glaciers once again formed as far south as New Mexico in the Rocky Mountains and the summer precipitation in northern New Mexico seems to have been two or three inches greater than the recent normal. The Neo-boreal closed in the mid-nineteenth century with the well-documented climatic change which was associated with a return to strong westerlies in mid-latitudes.

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The authors note that circular reasoning must be avoided when trying to relate climate to biotic complexes. For example, the Köppen climatic classification scheme essentially starts with biotic distributions, for which arbitrarily selected climatic parameters are sought which best fit the boundaries of the biotic regions. Generally these are simple parameters, implying that single variables are limiting factors along the boundaries of the biotic regions. There is no 'a priori' reason to assume that this is true. The perhaps fortuitous parallelisms of isotherms and biotic boundaries are often the basis for climatic regionalizations, ignoring the interactions of climatic parameters which might reasonably determine the suitability of the climatic environment for a particular biotic type.

The authors have developed the discussion of this paper on the basis of the correspondence between independently derived climatic and biotic charts. They assumed that the characteristic airmass combination as it varies during the year at a given place represents the significant climatic complex operating as an ecological control on the biotic community of that place.

The authors examination of the literature suggested that there is inadequate recognition that the impacts of minor climatic variations are greatest at the boundaries of a biotic zone; ecotones are sensitive to climatic change and the central parts of biotic zones are far less so.

1. BUDYKO, M.I.

2. 1969

3. Climatic change.

4. Soviet Geography 10:429-457

5. a. Northern hemisphere

   b. Nil

   c. Climate (temperature, insolation), Climatic change (hypotheses, proxy data)

6. In this paper the methods of physical climatology were used to explain climatic variations during the contemporary epoch and in the geological past. Contemporary climatic change was found to depend to a considerable extent on variations in atmospheric transparency. These variations, which change the amount of solar radiation reaching the earth's surface, were associated with the changeable level of volcanic activity. Climatic changes in the geological past were also explained in terms of variations in atmospheric transparency and the changing distribution of the earth's land and sea areas, which influenced circulation in the hydrosphere. On the basis of established regularities in past climatic change, a possible future trend of climatic evolution was suggested. Although the current cooling trend could conceivably lead to renewed expansion of glaciation, this was considered highly unlikely in view of the increasing amount of heat generated by man's growing use of energy. The additional heat may be sufficient in the long run to melt the polar ice and introduce a climate into the middle and high latitudes typical of warm interglacial epochs. Actually, even before this, technology may enable man to eliminate the polar ice artificially.

The principal results of the empirical study of past climates can be summarized by the following conclusions.

1. Climatic conditions that prevailed over the last few hundred million years differed markedly from those of the present. Throughout this entire segment of time, except for the relatively brief Quaternary period, the difference in temperatures of the low and high latitudes was relatively small, with tropical temperatures roughly at present levels and temperatures in the middle and high latitudes substantially higher than those observed at the present time.

2. The evolution of the present contrast between the temperatures of the equator and those of the poles began about 70 million years ago, at the start of the Tertiary period. That process was rather slow, and by the beginning of the Quaternary (about a million years ago) the difference of temperatures at the high and low latitudes was still substantially less than the present difference.

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3. In the Quaternary period, the temperature dropped sharply in the high latitudes in conjunction with the beginning of polar glaciation. Glaciation in the northern hemisphere was subjected to considerable fluctuation in the course of which it increased several times, reaching the middle latitudes, and then retreated again to the higher latitudes. The last advance of the ice sheet in Eurasia ended about 10,000 yr ago, and since then the permanent ice cover in the northern hemisphere has been limited largely to the Arctic Ocean.

4. In the last 10,000 yr, thermal conditions in the higher and middle latitudes have continued to change as a result of substantial fluctuations in the area covered by the polar ice.

5. In the last century, for which instrumental data are available, climatic fluctuations continued. The first half of the 20th century witnessed a warming trend that was particularly evident in the 1920's and 1930's. This trend ceased in the 1940's and was followed by a cooling trend, which has not yet reached the magnitude of the preceding warming trend. Present climatic change is most evident in the higher latitudes of the northern hemisphere.

Analysis of air temperature anomaly maps indicated that the warming period beginning at the end of the 19th century ended about 1940 and gave way to a cooling trend. In this process the northern hemisphere temperature, after having risen by 0.6° C during the warming trend, again dropped by 0.2° C by the middle 1950's. A relatively brief warming trend with a smaller amplitude also occurred in the last few years of the 19th century.

These findings confirm the existence of noticeable climatic fluctuations of a global character. The causes of these fluctuations have been discussed widely in the literature. Among the hypotheses presented is the supposition that the earth's thermal regime might be affected by change in atmospheric transparency for the flux of short-wave radiation because of changes in the amount of atmospheric dust. Some authors have also related contemporary climatic change to the effect of changes in the amount of carbon dioxide on long-wave radiation, to the instability of solar radiation, a . to self-fluctuations of the system consisting of the atmosphere, the oceans and polar ice.

It was first noted at the beginning of the 20th century that the mean amount of direct solar radiation reaching the earth's surface under cloudless conditions may vary noticeably from year to year, but this parameter also varies over longer periods, of the order of decades. It was established that sharp reductions of solar radiation occur when the lower layers of the atmosphere are filled with volcanic dust after volcanic eruptions. In such cases, the global magnitude of direct

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radiation may drop by 10 to 20% over a period of several months. After great eruptions, the global mean temperature has dropped by a few tenths of a degree.

Two maxima for solar radiation have been noted, a short maximum at the end of the 19th century and a longer maximum in the first half of the 20th century with its highest values in the 1930's. It might be supposed that the increase in radiation at the end of the 19th century resulted from the clearing of the atmosphere after the spread of volcanic dust from the Krakatau eruption. The next reduction of radiation could have been the result of eruptions of Mount Pelee and other volcanoes. The rise of radiation during 1915 to 1920 can apparently be attributed to an increase in transparency after the dust from the Katmai eruption had settled.

The author reviewed literature and mathematical models to show that changes in incoming solar radiation caused by instability of atmospheric transparency do have a significant effect on climate and evidently represent the basic cause of contemporary climatic change. This conclusion does not exclude the possibility that other factors may affect climate, but they evidently play a less significant role compared with changes in atmospheric transparency.

When a layer of volcanic dust is present in the atmosphere, dire radiation decreases inversely with the optical mass of the atmosphere; for example, direct radiation decreases with the mean elevation of the sun. This means that direct radiation decreases to a greater extent in higher latitudes than in lower latitudes, and more greatly in winter than in summer. This effect is even more pronounced in total radiation because the ratio of the decrease of total radiation to the decrease of direct radiation also increases inversely with the mean elevation of the sun. For these reasons, with increasing latitude there is a progressive increase of temperature change after volcanic eruptions.

Data on temperature anomalies show that during the general warming trend in the first half of the 20th century, the differences between temperatures in the higher and lower latitudes dropped by 2° C, by several percent of the existing mean meridional temperature gradient. This change in the temperature field significantly affected the circulation in the atmosphere and the hydrosphere. The circulatory changes, in turn, had an effect on the temperature field and were reflected in such climatic elements as the hydrologic cycle and precipitation. It appears that the reduction of the meridional temperature gradients in the 1920's and 1930's weakened the zonal circulation in the middle latitudes, thus affecting precipitation in eastern Europe and producing a drop in the level of the Caspian Sea.

Continued ...

The author made several assumptions about the likely character of climatic changes in the future. The amount of dust in the atmosphere in the late 1960's was relatively large, reducing the direct radiation reaching the earth's surface. On the basis of the relatively low rate of fallout of dust in the stratosphere and the effect of the earth's thermal inertia, the negative anomaly of the earth's temperature in the late 1960's could be expected to continue in the next few years. Further climatic change would depend on the level of volcanic activity, with prolonged intensification of volcanism leading to general cooling and an advance of glaciers, and a reduction of volcanism to a warming trend and glacier retreat. Forecasting of expected climatic change would require more detailed information on volcanic eruptions, the dust content of the atmosphere, and the solar radiation regime. The author suggested that natural fluctuations will probably not substantially alter the meteorological regime of the earth over the next few hundred years. From the physical considerations described in the article and the available data on the history of climate over the last few thousand years, it appears that over the next few centuries significant climatic fluctuations could occur only in the high latitudes, where the meteorological regime is a sensitive index of small changes in climate.

1. BUDYKO, M.I.

2. 1974

3. Climate and life.

4. English version edited by D.H. Miller, Academic Press, New York. 508 p.

5. a. Northern hemisphere

   b. Hil

   c. Climate/growth (direct relationships, latitude)

6. In numerous experimental investigations, it has been established that the "coefficient of useful activity" of photosynthesizing vegetation (that is, the ratio of the heat converted in synthesizing biomass to the general amount of incoming solar energy) is very small and usually does not exceed 0.1 to 1.0%. Furthermore, vegetation also expends water resources rather uneconomically. The productivity of transpiration (the ratio of the increase in dry mass of the plant to the water expended in transpiration in a given interval of time) usually has a value from 1/200 to 1/1,000 (most often about 1/300). There is evidence that such copious transpiration does not correspond to physiological needs of the plant and is, to a considerable extent, a waste of water. These two fundamental facts indicate that, in natural conditions, vegetation assimilates only a small part of the available energy and water resources. Therefore, to investigate the relation of plant productivity to climatic factors, it is important to clarify the factors that restrict the utilization of resources in the synthesis of biomass.

Under conditions of sufficient moisture, vegetation productivity is most affected by two factors - photosynthetically active radiation and temperature. The effect of radiation and temperature on the productivity of vegetation is complex. Radiation under actually existing conditions is always a factor that is in the "minimum". This is associated with the constant shortage of radiation at the lower and partly shaded leaves of vegetation. The temperature influence on productivity has a quite different character: a rise in temperature above a certain limit lowers productivity substantially. The author presented data that indicated a relationship between vegetation, productivity and the sum of temperatures above 10° C, which suggests the possibility of using summed temperature as an index to characterize the effects of both the radiation regime and the temperature.

The author's calculations indicated that the diminution in biomass in forests with an increase in latitude depends most of all on the reduction in duration of growing season, while the effect of lower air temperature during the growing season and that of a change in radiation turn out to be less important.

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The author presented a graph in which empirical values of the annual productivity of natural plant cover (the annual increase of organic matter in the aerial and underground portions of vegetation) was related to the ratio R/Lr in which R = radiation in kcal/cm^2/yr and Lr = the radiative index of dryness which is the amount of heat required to evaporate the annual precipitation. The graph indicates that changes in productivity in relation to the index of dryness are rather similar at different levels of radiation balance.

In recent years, it has been established that in the contemporary epoch, climatic conditions have been characterized by considerable instability. Consequently, changes in the components of the earth's energy balance, amounting to several tenths of one percent of the incoming solar radiation, may have an appreciable effect on the location of ice cover and on the climate of middle and high latitudes. From this point of view, the question about the possible influence of the energy of photosynthesis on meteorological processes requires some attention. The author noted that such an influence is restricted by the comparatively rapid return into the atmosphere of the energy assimilated in the course of photosynthesis, as a result of the general biological circulation converting this energy into heat. Climatic conditions are therefore affected by the difference between the energy used in photosynthesis and the amount of heat obtained as a result of decay of organic matter. This difference can make up only a small portion of the energy expenditure in photosynthesis, and its climate-forming importance for the contemporary epoch is probably insignificant. Vegetation cover produces the greatest effect on climate, not as a result of the solar energy conversion in photosynthesis, but because of the effect of transpiration on the balances of heat and moisture and as a result of vegetation-induced changes in the aerodynamic roughness of the earth's surface.

In summary, the author's models showed that the natural vegetation cover uses only a small portion of the incoming solar energy for creation of organic matter in the course of photosynthesis. A portion of this organic matter is disbursed by autotrophic plants for their own respiration and by atrophy of some parts of a plant in the course of its development. As a result, the net productivity of plants often does not exceed half the quantity of matter created by photosynthesis.

1. BUDYKO, M.I.

2. 1974

3. Climatic changes.

4. Translated 1977 by the American Geophysical Union, Waverly Press, Baltimore, Maryland. 261 p

5. a. Northern hemisphere

   b. Nil

   c. Climatic change (hypotheses, proxy data), Climatic variation (temporal, temperature)

6. This text gives a brief description of climatic conditions in the past and a survey of various opinions of the causes of climatic changes. A semi-empirical theory of climate is applied to clarify the causes of natural climatic changes of the past and present. A final chapter outlines the influence of climatic changes on the evolution of living organisms.

The author concluded that the warming that reached its peak in the 1930's apparently resulted from an increase in transparency of the stratosphere which led to an increase in solar radiation flow to the troposphere. This, in turn, led to an increase in the average global temperature at the earth's surface. It seems possible that the changes in stratospheric transparency that took place during the first half of the 20th century were related to volcanic activity. The author stressed that this warming is of great importance for revealing the mechanism of climatic changes, since it is the only one that has been comprehensively and exhaustively studied by means of reliable instruments at many research centres. He urged that any quantitative theory of climatic fluctuations must be backed by data referring to the warming during the first half of the 20th century.

In the final chapter of this text, it is pointed out that all living organisms are highly dependent on climatic resources. The question therefore arises whether organisms are able to vary climatic conditions to make them more favourable. Typically, not more than a fraction of 1% of the energy of solar radiation is used in the biological cycle. Consequently, living organisms cannot substantially vary the energy conditions of climatic processes. In general, climate exerts a vast influence on the activity of animals and plants, whereas the inverse relations between living organisms and climate are comparatively weak.

The productivity of an autotrophic plant cover at first increases slowly as its biomass grows because the surface of leaves is still small; in a middle phase, productivity increases more rapidly and then decreases again when there is a decrease in photosynthesis. The latter occurs when the lower strata of leaves are significantly shaded. Productivity begins

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to decrease at high biomass, when the additional respiration of a large biomass is not entirely compensated by photosynthesis.

A close relation between geographic zones and climatic conditions has been established by Grigor'ev and the author, who compiled a table of geographic zonality, as summarized below.

	Radiation balance of earth's surface ($kcal/cm^2/yr$)	
Aridity index	Less than 0 (high latitudes)	0-50 (subarctic & middle latitudes)
Less than 0	Perpetual snow	-
0 - 0.25	-	Arctic desert
0.25 - 0.40	-	Tundra
0.40 - 0.60	-	Northern & middle taiga
0.60 - 0.80	-	Southern taiga & mixed forests
0.80 - 1.00	-	Deciduous forest & forest steppe
1.00 - 2.00	-	Steppe
2.00 - 3.00	-	Semiarid land
Over 3.00	-	Desert

Forest vegetation predominates at all latitudes under excess moisture conditions, but not under extremely excessive moisture conditions (aridity index below 0.40). In this case forest vegetation is replaced by tundra at higher latitudes and by wetlands at low latitudes. Each gradation in moisture is characterized not only by the type, but also by productivity of the plant cover. Grigor'ev and the author proposed that productivity of the natural plant cover increases as moisture conditions approach the optimal state for a given radiation balance and that productivity increases as the radiation balance increases under fixed moisture conditions.

The following factors were listed as fundamental natural causes of climatic change:

1. Volcanic activity - A study of contemporary climatic changes shows that fluctuations in volcanic activity can affect climatic conditions for years and decades. Volcanism can also influence climatic changes over periods in the order of centuries and over longer intervals of time.

Continued ...

2. Astronomical factors - A change in the position of the earth's surface relative to the sun will create climatic changes with time scales of tens of thousands of years.

3. Composition of the atmosphere - A decrease in the content of carbon dioxide in the atmosphere particularly influenced the climate towards the end of the Tertiary and Quaternary periods. Bearing in mind the rate of this decrease and the air temperature changes corresponding to it, the author concluded that the influence of natural variations in carbon dioxide content is of importance for intervals of time greater than 100,000 yr.

4. Structure of the earth's surface - A variation in topography and related variations in the position of the shores of seas and oceans change climatic conditions over large spaces for periods of hundreds of thousands and millions of years.

5. Solar constant - Slow fluctuations of solar radiation are possible as a result of the evolution of the sun, setting aside the question of the existence of short-period fluctuations in the solar constant. These fluctuations can substantially influence climatic conditions over periods of time lasting at least 100 million years.

Variation in the amount of carbon dioxide in the atmosphere has an effect on the total mass of living organisms. The major portion of this biomass consists of autotrophic plants, the amount of which is controlled by their photosynthesis. This dependence has a very simple explanation. The consumption of organic matter by autotrophic plants can be considered proportional to plant mass. Inasmuch as the total amount of photosynthesis is equal to the expenditure of organic matter and the rate of photosynthesis is approximately proportional to the concentration of carbon dioxide, the mass of vegetation is also proportional to the concentration of carbon dioxide. This conclusion pertains mainly to those cases in which the amount of water, minerals and other growth factors are in sufficient supply. From this it follows that during the geological past, when the carbon dioxide concentration was considerably higher than it is now, the mass of plant cover on land was probably greater than at present. Thus, the process of carbon dioxide decrease in the atmosphere and hydrosphere was probably accompanied by a gradual decrease in the mass of autotrophic plants and consequently in the mass of all living organisms on our planet.

The influence of astronomical factors on future climate may significantly intensify with a further decrease in the content of carbon dioxide in the atmosphere. Since such a trend has prevailed for many millions of years, it is highly likely that the amount of atmospheric carbon dioxide will continue to decrease in the future, counteracted only by man-made increases in carbon dioxide levels. Extrapolation can be used to estimate the period of time over which the carbon dioxide concentration of the atmosphere will decrease from the value it had prior to the epoch

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of rapid industrialization (0.029%) to a value at which total glaciation of the planet (0.015%) is possible. The difference between these two values is close to the change in carbon dioxide concentration that has come about from the beginning of the development of Quaternary glaciations to the present. Thus, one could conclude that total glaciation of the earth could occur in a period of one million years. This period would be less if one considers that the general tendency toward the development of glaciation resulting from a decrease in the concentration of carbon dioxide is accompanied by a periodic increase of ice cover due to a variation in the position of the earth's surface relative to the sun. Thus, total glaciation of the earth could begin in several hundreds of thousands of years.

The author predicted that the long-term continuing decrease in carbon dioxide concentration will be accompanied by a gradual drop in productivity of autotrophic plants and a lower total mass of living organisms on the earth. The author indicated that the probability of total glaciation in the course of the earth's natural evolution increases if we take into account existing tendencies toward an increase in the elevation of the continents at a number of locations in the northern hemisphere.

The author's model indicates that the potential rise in temperature due to growth in energy use during the first half of the 21st century will exceed the temperature changes that occurred in the first half of the 20th century as a result of natural causes. Temperature will subsequently increase rapidly, which will lead to great changes in global climate. Thus, growth in the use of energy consumed by man may exert a substantial influence on future climate. The second factor that may significantly change the climate is possible increase in the carbon dioxide concentration in the atmosphere.

Superimposed upon these potential changes will be a continuation of the comparatively minor variations in the modern climate which are mainly the result of changes in the concentration of stratospheric aerosol particles that influence solar radiation flux. These changes are brought about by volcanic activity. In recent decades global climate has been affected by anthropogenic factors which include an increase of carbon dioxide and aerosol concentrations in the atmosphere. Such factors could result in drastic changes of climate of great practical significance to man. The author stressed the importance of developing methods to control climatic modifications. One such method is to maintain a certain minimum level of aerosol concentrations in the stratosphere.

1. BUDYKO, M.I., K. Ya. VINNIKOW, O.A. DROZDOV and N.A. YEFIMOVA

2. 1979

3. Impending climatic change.

4. Soviet Geography 20:395-411

5. a. U.S.S.R.

   b. Mil

   c. Climatic change (hypothesis, proxy data), Climatic variation (regional, temporal, temperature, precipitation)

6. This paper is an attempt to predict climatic change within the U.S.S.R. for the end of the 20th century and the first quarter of the 21st century. The forecast is based on the assumption that the CO_2 content in the atmosphere will increase and that the earth's heat regime is sensitive to changes in CO_2 content. Relatively small changes in the global heat regime were calculated on the basis of observations by the world network of weather stations. Greater changes were evaluated through the use of palaeoclimatic data.

Over the last 100 yr there have been two warming trends. The first warming trend, starting at the end of the 19th century, reached a maximum in the 1930's when the mean temperature of the northern hemisphere rose by 0.8° C. This was followed by a cooling trend until the mid 1960's, with the mean temperature declining by 0.4° C. The cooling which ceased in the mid-1960's appears to have been succeeded by a new warming trend.

The use of relatively simple climatic models makes it possible to calculate, with fairly high precision, the secular march of the mean temperature in the northern hemisphere, which is a key indicator of climatic conditions. The average values of this temperature parameter, averaged out over time intervals of several years, are determined mainly by atmospheric transparency and by CO_2 concentration, whereas the impact of instability in atmospheric circulation and in ocean currents as well as other random factors tends to be relatively minor. The role of these random factors increases for shorter time intervals and for more limited territories.

The study of climatic change has shown that fluctuations in the mean temperature for the northern hemisphere or for the earth as a whole are closely related to changes in the meridional temperature gradient. A warming trend is associated with a reduction, and a cooling trend with an increase in the gradient. Calculations using climatic models have shown that the relative temperature change at different latitudes tends to be fairly similar during temperature fluctuations caused by changes in atmospheric transparency and in CO_2 content.

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Fluctuations in the meridional temperature gradient greatly affect atmospheric circulation and precipitation. It has been established that a warming trend results in a decline of precipitation over large continental areas, and a cooling trend in an increase in precipitation. These changes are only part of the fairly complex picture of fluctuations in precipitation in various geographical regions during global warming or cooling trends.

Polar sea ice also has significance for contemporary climatic change. Because of its high albedo, an increase in the ice-covered area leads to further cooling and a reduction in ice-covered area to further warming. Calculations have shown that melting of the polar sea ice would raise the mean temperature in the higher latitudes by at least 15° C. Such a temperature rise and the resulting increase in evaporation from the ice-free surface of the Arctic Ocean could lead to an increase in precipitation over much of the continental area in the higher and middle latitudes.

By the authors' estimates, the increase in amount of heat generated by human activity was not expected to affect global climate before the second quarter of the next century. The climatic impact of the increase of man-made aerosols was thought to be limited, and it was unlikely that the amount of aerosols would increase significantly. It was also unlikely that the stratosphere would become polluted with sufficiently large amounts of freon and other gases that might modify the radiation and heat regime of the atmosphere.

Based on the above considerations, the authors made a series of predictions regarding likely climatic change over the late 20th and early 21st centuries. These predictions are presented in a summarized form as follows.

Previous studies indicated that CO_2 concentrations rose from 0.029% to 0.033% over the 100 yr period ending in the mid 1970's. The CO_2 concentration will rise to 0.037% by 1990 and roughly 0.065% by the year 2025. Assuming a constant albedo, the temperature rise produced by a doubling of CO_2 concentration would be 3.5° which agrees well with estimates obtained by use of the climatic models.

The expected increments in ground-layer temperatures (+°C) in various latitudinal zones, on the assumption that the yearly mean temperature for the northern hemisphere would rise by 0.5° C by 1990 were as shown on the following page:

Continued ...

Budyko, M.I., K.Ya. Vinnikow, O.A. Drozdov and N.A. Yefimova. 1979.
Continued

	20–40°N	45–60°N	65°N	70°N	75–80°N
Winter	+0.4°C	+0.6°C	+1.4°C	+2.0°C	+2.4°C
Spring	0.3	0.5	0.6	0.6	0.6
Summer	0.2	0.4	0.8	0.8	0.6
Autumn	0.3	0.6	1.0	1.1	1.1

The authors pointed out that these temperature changes assumed no significant change in the transparency of the atmosphere. An increase in transparency would accelerate the warming trend, and a reduction would slow the process.

If the mean annual temperature of the northern hemisphere were to increase by 0.5° C, the temperature sum above 10° C would rise by 1400 to 1800° at the latitude of the Arctic Circle, by 1200 to 1600° in the latitudinal zone between 50 and 60 degrees, and by 1300 to 1600° further south. The temperature zone characterizing the conditions of the growing season would shift northward by 1 to 3 degrees of latitude by 1990, and by 10 to 15 degrees of latitude by 2025. The predicted temperature sums above 10° C along a gradient at 30° E longitude were as follows:

	Present	1990	2025
66.5° N Latitude	1000°	1300°	2400°
60.0° N Latitude	1650	2000	2900
55.0° N Latitude	2100	2300	3400
50.0° N Latitude	2600	2750	3750
47.0° N Latitude	3200	3300	4500

For the assumed temperature increase by 1990, there would be a 15% reduction of mean annual precipitation in some areas of the U.S.S.R. This reduction in precipitation would be caused by a decline in intensity of atmospheric circulation and in the transport of water vapour from oceans to continents associated with a reduction of the meridional temperature gradient characteristic of a warming trend. By the year 2025, when the polar ice could be expected to vanish under the impact of an increase in CO_2 concentration, precipitation would be affected by an increase in evaporation from the polar seas, by the overall warming trend and by a reduction of temperature contrasts between latitudinal zones. It was suggested that precipitation in the present tundra zone would be 500 to 600 mm greater than at present. Further south, up to a line running from Riga to Tselinograd, the increase in annual precipitation would be roughly 200 to 400 mm, with little change south of that line.

In the period preceding the melting of polar sea ice, the expected decline of the meridonal temperature gradient could upset the stability of atmospheric circulation and enhance the frequency of particularly

Continued ...

Budyko, M.I., K.Ya. Vinnikow, O.A. Drozdov and N.A. Yefimova. 1979.
Continued

severe droughts in the middle latitudes of continents. The warming trends of the 1930's and of the first half of the 1970's were examples of this kind of change in the precipitation regime. Enhanced warming would further increase the potential evaporation at all latitudes, because of the direct impact of higher temperatures and because of an increase in the radiation balance of the earth's surface resulting from a rise in CO_2 concentration and a reduction of albedo in the absence of snow cover.

The annual sums of radiation balance were expected to rise by 10 to 12% in the southern and central regions of the U.S.S.R., and by 30 to 50% or more in the north, in west Siberia and in northern Kazakhstan. The expected change in potential evaporation values by the year 2025 were an increase of 200 mm/yr in the western portion of the European U.S.S.R., 300 mm/yr in the central and northeast portions and 400 to 500 mm/yr in the southeast.

1. BUSBY, John R., L.C. BLISS and Catherine D. HAMILTON

2. 1978

3. Microclimate control of growth rates and habitats of the boreal forest mosses, Tomenthypnum nitens and Hylocomium splendens.

4. Ecological Monographs 48:95-110

5. a. Canada; Index map NM-11; Alberta; B.19a

   b. Nil

   c. Biomass (moss/lichen), Climate/growth (direct relationships, microclimate)

6. The slow growth rates of bryophytes make it difficult to evaluate correlations between growth and environmental factors. The objectives of this study were: to measure the growth rates of bryophytes during the snow-free season; to correlate these growth rates with physical environmental factors; and to investigate those factors likely to control growth rates and habitat limits of species adapted to contrasting light and moisture regimes. The field study site was located 16 km southwest of Edson in west central Alberta (116 36 W, 53 29 N).

Tomenthypnum nitens forms tall turfs in fens where the tree and shrub canopy is sparse and the water table is close to the surface. The feather moss species, Hylocomium splendens, Pleurozium schreberi, and Ptilium crista-castrensis form wefts in shaded and better drained locations. In 1975, net production of T. nitens averaged 190 $g/m^2/yr$, and net production of the feather moss species averaged 79 $g/m^2/yr$. The latter estimate was comparable to the 44 to 58 $g/m^2/yr$ recorded by Weetman and co-workers in an undisturbed black spruce stand in Ontario, and the 38 to 150 $g/m^2/yr$ recorded by various Scandinavian researchers for annual moss production in spruce forests, subalpine birch forests and in willow thickets. The authors' estimates apply to mosses in undisturbed habitats. Moss growth rates would be expected to be lower where tree or shrub canopies are disturbed; it has been shown that tree canopy removal kills feather mosses.

Growth of T. nitens is controlled by the balance between evaporation rate and water transport to the canopy surface. Growth of the feather mosses is controlled by rainfall frequency and degree of protection from evaporation stress. Seasonal growth of T. nitens appears to depend on the total amount of precipitation rather than frequency or intensity as in the case of the feather mosses. Although rainfall is probably the ultimate controlling factor, growth of T. nitens is limited by low temperature at the beginning and end of the season and by a falling water table during the summer.

Solar radiation has complex and indirect effects on bryophyte growth rates. Higher radiation levels apparently have a direct deleterious

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effect on feather mosses, but do not appear to affect T. nitens, or at least not to the same extent. Feather mosses could tolerate high light levels where the local microclimate reduced evaporation stress.

In this study an estimate was made of the number of days in each month during which the moss was wet enough to photosynthesize. Days per month in which rainfall was more than 1 mm were noted, on the assumption that rainfall of less than 1 mm would have been completely intercepted by the tree canopy. The authors concluded that moss wet days, through the influence of water on photosynthesis, is the most influential environmental parameter for feather moss growth.

1. CARDER, A.C.

2. 1965

3. Northwestern Canada's climate: its effect on crop growth and development.

4. Agricultural Institute Review 20(3):20-22

5. a. Canada; Index maps (all in Alberta, British Columbia, Northwest Territories, Yukon); all boreal forest sections in Alberta, British Columbia, Northwest Territories, Yukon

   b. Nil

   c. Growing season (length, degree-day totals, frosts)

6. Although this article does not deal specifically with forest vegetation, it summarizes climatic features that favour plant growth in the boreal zone in western Canada. The boreal zone extends from the margin of the tundra far to the south, at one point just east of the Rocky Mountains to 52° N; but on the average its limits approximate 54° N except in the extreme west where the influence of the Pacific Ocean pushes its southern extremity well north. Like the tundra, the boreal zone has the pecularities of coldness, wide differences in diurnal periods of light and darkness, mostly low precipitation, and low evaporation. These characteristics intensify toward the north.

One of the more important reasons for the continued presence of coldness in the boreal zone is the high albedo of the earth's surface, induced by the high incidence of ice, snow and cloudiness. Another is the long distance of these regions from warm seas and other warm areas so that little advected heat reaches them. Moreover, warm air currents from such areas tend to be diverted by the cold, heavy air masses inherent in northern regions.

Low precipitation is a feature of the boreal zone in northwestern Canada. It varies from over 76 cm annually in the southwest to less than 25 cm in the extreme north. The principal reasons for this lack of precipitation are: 1) low specific air humidity because of cold temperature; 2) the settling of cold air masses; and 3) the lack of convection storms because of the inability of the sun to cause sufficient warming for vigorous atmospheric turbulence.

Several factors operate in the western boreal zone that are favourable to plant growth and fruiting. Possibly the most important is the influence of warm Pacific air masses which tend to follow set storm tracks. One such track crosses northern British Columbia or southern Yukon in a northeasterly direction until it is pushed southward by the heavy air of the eastern Arctic. Storm centres that follow this track, therefore, usually cross the Rocky and Mackenzie mountains and descend into the Mackenzie River basin before being directed on a southeasterly course.

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Climatic requirements for the successful production of cool-season crops in northwestern Canada are: 1) sufficient moisture; 2) a sufficiently long period free from killing frosts, with -2.2° C taken as a killing frost; 3) a sufficiently long "growing season", basis 5.5° C; and 4) a sufficient amount of effective heat, based on growing degree days above 42° F. Despite the generally low precipitation, the first condition seems to be satisfied in most instances, while the remaining conditions would seem also to be met except in the localities farthest north in the boreal zone.

Temperature requisites for the successful production of cool-season crops are summarized in the table below.

	Frost-free period days	Period free from killing frosts, days	Vegetative period, days	Degree days*
Requisite threshold		80	110	1000
Lacombe	81	116	170	1972
Beaverlodge	101	132	170	1913
Fort Vermilion	72	104	147	1859
Fort Simpson	85	120	137	1800
Wrigley	90	111	132	1673
Norman Wells	90	117	121	1472
Fort Good Hope	65	98	113	1460
Fort McPherson	77	103	104	1114
Aklavik	75	106	99	925
Whitehorse, Mile 1019	23	54	119	801

* basis 42° F

1. CARLISLE, A.

2. 1976

3. The utilization of forest biomass and forest industry wastes for the production and conservation of energy.

4. Department of the Environment, Canadian Forestry Service, Ottawa. 54 p

5. a. Canada; Index maps (all in boreal region); All boreal forest sections in Canada

   b. Nil

   c. Biomass (tree)

6. This report, which reviews the potential for using forest biomass and forest industry wastes for the production and conservation of energy, is based on discussions by scientists, program managers and economists at a Canadian Forestry Service Workshop held at Petawawa Forest Experiment Station, Chalk River, Ontario, in September 1975. The author supplemented the discussions with other information sources. The portion of the review that dealt most closely with biomass estimates for boreal ecosystems is summarized in the paragraphs below.

In the past there have been controversies about the ecological consequences of large scale clear cutting, but usually this has been in the context of long rotations and roundwood extraction, and apparently nutrient loss has not so far been serious. It is another matter, however, when one proposes whole tree harvesting on short rotations. A high proportion of a tree's nutrients are located in the leaves and smaller branches, and removal of such nutrients from the site poses serious questions. The probability of considerable net nutrient loss is very high. To illustrate the point the author made an estimate based on very approximate figures. Consider, for example, a plantation of fast-growing tree genotypes such as poplars, with a mean annual stem increment of about 17.5 m^3/ha/yr, equivalent to about 7,566 kg/ha/yr on an air dry basis. Converted to an oven-dry basis, by allowing 12% moisture content, this is about 6,658 kg/ha/yr. Allowing about 20% for foliage, amounting to 1,332 kg/ha/yr, the total above-ground production is about 7,989 kg/ha/yr.

If one assumes that stem wood and bark have an approximate nitrogen content of about 0.5% of oven-dry weight, and the leaves a nitrogen content of about 2.0% of oven-dry weight, averaged from aspen data, if all the above-ground parts of the trees were to be harvested there would be about 59 kg/ha/yr of nitrogen taken out of the system. Nitrogen enters the system in rainfall and possibly by fixation of atmospheric nitrogen. In the north temperate zone, about 4 to 5 kg/ha/yr of nitrogen came down in precipitation. This results in a nitrogen deficit of about 54 kg/ha/yr. No estimate for atmospheric nitrogen fixation is available,

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but on fertile soils, such as those favoured by poplar, nitrogen fixation would be expected, but there would not be more than a few kilograms per hectare per year. Even allowing for fixation, the nitrogen deficit would probably be about 50.4 kg/ha/yr. Other researchers have considered the possibility of managing an "energy forest" in Canada's boreal forest, based on estimates that for short rotations of 15 yr the average loss of nitrogen would be 17.7 kg/ha/yr, a rate of loss that could not be sustained for many years without a serious drop in growth rate.

For slower growing species and long rotations the loss would not be so serious, as rainfall would be bringing nutrients into the site over a long period. It should be remembered that on soils of low fertility on the Canadian Shield, nitrogen-fixing organisms are not likely to be very active, and one cannot expect much nitrogen replacement to come from this source. Also there will be some nitrogen losses by percolation down the soil profiles, quite apart from logging losses.

1. CERMAK, Vladimir

2. 1971

3. Underground temperature and inferred climatic temperature of the past millenium.

4. Palaeogeography, Palaeoclimatology, Palaeoecology 10:1-19

5. a. Canada; Index map NM-17; Ontario; B.4

   b. Nil

   c. Climatic change (proxy data)

6. There is considerable evidence from different fields of investigation that the world climate has undergone significant variations, even during the last 1,000 yr. The effect of the change of temperature on the earth's surface in the past may be preserved at depths of several hundred metres below the surface. Any change at the surface is propagated downwards, and the author has shown that the detailed record of temperature with depth can be used to trace climatic history. Data were obtained from two boreholes in northeastern Ontario. The measured underground temperature clearly confirmed the notably warm climate that lasted from about A.D. 1000 to 1200 and the following cold period after 1500.

Both these recent climatic extremes, known as the "Little Climatic Optimum" and "Little Ice Age", are well substantiated, but the magnitude of the temperature variations is uncertain. The relation between mean annual air temperature and surface (ground) temperature depends very much on the precipitation regime and the duration of snow cover.

The results indicate for the Kapuskasing area a surface temperature during the Little Climatic Optimum at least 1.5° C higher than the reference value: the mean temperature during the Little Ice Age was about 1° C below this reference value. A remarkable increase in excess of 3° C is inferred for the period since about 1850.

1. CHAN, Yip-Hoi

2. 1978

3. Simulation of land-use patterns affecting the global carbon cycle.

4. The University of Tennessee, Knoxville. Ph.D. Thesis. 170 p

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels)

6. Past increase of atmospheric CO_2 involves significant contributions from both fossil and nonfossil (biospheric) sources. The latter are controversial, partly because these CO_2 releases may be balanced by accelerated regrowth following clearing of some forests, while other forest areas have been converted to agricultural or other nonforest land. A simulation model was used to reconstruct changes since 1860 and to project four hypothetical future scenarios of CO_2 levels. Areal extent of tropical forests, other wooded ecosystems, and nonforests were incorporated into the model. Rapidly and slowly exchanging pools of carbon per unit area, and net primary production for each pool and ecosystem group, were projected by integrating income-loss differential equations.

Estimated cumulative releases of CO_2 from fossil fuels (plus cement) of 120 Gtons of carbon (1 Gton = 10^9 metric tons) from 1860 to 1970 were assumed to equal the release from forest clearing. Limits of exploitable forest area and biomass were evaluated and found to have the potential to contribute much less future CO_2 than the usable coal, oil, gas, and oil shale. Ultimate release from the latter (7500 ± 2500 x 10^9 tons of C) could increase atmospheric CO_2 manyfold, possibly doubling the assumed 1860 levels as early as the year 2025 if one assumed a "nominal" scenario in which releases expanded only slightly less rapidly than at present.

Depending on the poorly known parameters that were estimated for organic production rates, cumulative storage, and the response of plants and soils to enhanced atmospheric CO_2, biospheric storage might reach higher levels for all scenarios than the estimates given by the author. However, maximizing such storage (and helping to minimize atmospheric CO_2 for any given energy policy) in real life would require very much closer understanding and wiser management of ecosystems than history has shown.

The author's review of recent literature revealed why there is uncertainty over whether the terrestrial biosphere is a source or a sink of atmospheric CO_2. The concentration of atmospheric CO_2 has been observed to increase steadily since 1958, but the annual increases

Continued ...

Chan, Y-H. 1978. Continued

approximate only 50% of the carbon dioxide released each year by fossil-fuel combustion. Until recently, it had been widely accepted that about 30% of the annual release was dissolved in the ocean and the remainder was assimilated by green plants. However, several studies by geophysicists and biologists in the two or three years preceding the author's study implied that the terrestrial biosphere is probably not a net sink for the excess CO_2 and may have functioned, in the past 100 yr, as a significant source of atmospheric carbon dioxide. The oceanographers, however, maintain that the ocean alone could not accommodate the amount of the excess CO_2 not remaining airborne. Increasing importance and controversy have thus arisen concerning the possibilities that trees and humus have been net sources or net sinks for atmospheric CO_2.

Deforestation is suggested as the main source of nonfossil carbon in the atmosphere. In the boreal and north temperate regions, the total area of forested lands is sometimes assumed to be roughly stable for the last 100 yr. However, in tropical, subtropical, and south temperate forests, clearing definitely prevails over reforestation and natural succession. Yet another source of nonfossil carbon is the soil humus which may contain from 1500 to 3000 Gtons of carbon. The losses to the atmosphere from soil carbon have been enhanced because of the increased oxidation from swamp drainage, field plowing, and disturbance after logging operations. However, the long-term trend of carbon loss from the soil could have been reversed through humus-building by certain agricultural practices in some well-managed, fertile areas. The possibility of net CO_2 loss from some areas and net storage in others leaves the global balance in doubt at this time. The author's objectives were to provide a finer discrimination of the biospheric submodel in a global carbon model and to focus on the role of terrestrial ecosystems as sources or sinks for the excess CO_2 released from human activities.

The author's estimates of trends in the area occupied by the boreal zone and the amount of carbon stored in that ecosystem are listed below in relation to the estimated totals for all wooded ecosystems on earth and the total terrestrial area (excluding glaciers, lakes, reservoirs, rivers).

	Estimated Area ($10^6 km^2$)			Estimated Carbon Pool Live (Gton)		
	Preagricultural	1860	1970	Preagricultural	1860	1970
Boreal (taiga)	10.10	9.5	9.0	101	88	81
Semiboreal	6.91	5.6	5.0	64	48	40
Total woodland	-	56.9	47.9	987	633	493
Total earth (minus water and ice)	-	130.9	130.9	-	698	562

1. CHAPMAN, L.J. and M.K. THOMAS

2. 1968

3. The climate of northern Ontario.

4. Department of Transport, Meteorological Branch, Toronto. Climatological Studies No. 6. 58 p

5. a. Canada; Index maps (all in Ontario); Ontario; (all boreal forest sections in Ontario)

   b. Nil

   c. Climate (precipitation, temperature, insolation), Growing season (length, degree-day totals, frosts)

6. The climate of northern Ontario may be classified as modified continental, the modification being mainly due to the presence of the Great Lakes on the south and, to a minor extent, Hudson Bay on the north. February is more than 5° F warmer than January in the far north, but this difference decreases to 2° F near Lake Superior. The Great Lakes are responsible for this lag in warming so that spring comes later in most of northern Ontario than in those sections of the prairie provinces that have comparable winter temperatures. In summer, a continuing succession of cyclonic storms sweeps over northern Ontario and warm, humid air masses from the south alternate with cooler and drier air from the north to give two or three days of fine weather followed by warmer, more humid weather, often with changeable winds and rain for a day or two. While the relative durations of the fine and stormy weather spells vary, this pattern is repeated many times each year in northern Ontario.

Studies of the longest available records in Ontario show that there has been a trend towards a warmer, drier climate in Canada since the 1880's. The major increase in temperature came in the 1890-1900 decade, following an unusually cold 1880-1890 decade. However, in northern Ontario, there has been no apparent trend towards warmer or colder temperatures since about 1910. The slight trend towards decreasing precipitation, which is apparent in southern Ontario, does not appear to exist in the northern part of the province. The authors point out that a trend in climate may persist, stop, or even reverse itself. Without understanding of the causes of these trends they cannot be predicted, and so the records of the last 30 yr may be accepted as the best basis for a description of climates that might be expected over the next two or three decades.

The length and warmth of the growing season are critical to agriculture and tree growth in areas where summers are short. The average date of occurrence of a mean temperature of 42° F (5.6° C) in spring is considered to coincide with the start of the growing season. The average length of the growing season, that is the period when mean temperatures are above 42° F, shows a mean duration of 160 days in the northern clay belt, in comparison to 210 days in Essex and Kent counties in extreme southern Ontario.

Continued ...

Chapman, L.J. and M.K. Thomas. 1968. Continued

The author presented an isopleth map showing the average number of growing degree-days accumulated throughout the growing season. These values were obtained by subtracting 42° F from the daily normal temperatures, the normal temperature for each day being taken from smooth curves drawn through monthly means. As an index of climate in relation to growth and development, the parameter of growing degree-days assumes a direct linear effect of temperature on plants. This is not strictly correct and another weakness is that it disregards day length. However, it is the most commonly used means of expressing both the length and warmth of the growing season as a single value. According to this criterion the North Bay, Sudbury, Sault Ste. Marie area, with over 2800 degree-days, has the longest growing season in northern Ontario. Considering the agricultural areas, the Rainy River-Kenora settlements have the next longest season followed by the Temiskaming clay belt and then the northern clay belt. The value for Kapuskasing in the latter area is 2160, which is about the same rating as that for Edmonton, Alberta, and is slightly greater than values for the central part of the Peace River district. The comparable figure for Harrow, representing the warmest part of the province of Ontario, is 4300.

Late spring and early fall frosts may result from either of two different types of weather: nights with cold northerly winds which produce a general freeze, or still, clear nights, when heat is lost by radiation and cold air drains off slopes into depressions to produce spotty frosts. The type of soil affects air temperatures on these still, clear nights, as more rapid cooling takes place over sands than over loams and clays, while still greater cooling is found over peat. Small clearings often act as frost pockets. Local temperature differences due to varied topography and soils cannot be stated precisely, but they often amount to 10° F. Bodies of water have an ameliorating effect on air temperature; areas on the lee side of lakes sometimes escape late spring or early fall frosts when other areas suffer damage. The frost maps presented in this report show the moderating effect of the Great Lakes and the opposite effect of the rocky ridges in the height of land area.

Although no two separate regions of the earth have exactly the same climate, the authors identified the foreign and Canadian regions with climates similar to those in northern Ontario. A narrow belt across northern Europe has a climate comparable to that of northern Ontario. In southern Norway and Sweden, the climate is similar to that of the warmest parts of northern Ontario, although winters are not quite as cold in Scandinavia. Winters are colder in Russia than they are in northern Ontario and data from stations near the Ural Mountains are quite similar to those from northern Ontario. Within Canada, climate similar to that of the northern clay belt extends in a broad belt eastward across Quebec to the lower St. Lawrence River valley. The Peace River district in northern Alberta has a similar length of growing season, but in Alberta the summer days are longer due to the higher latitude. Also the fact that the Peace River district is much drier than northern Ontario results in it being a good grain-growing area.

1. CHRISTIE, J.M. and R. LINES

2. 1979

3. A comparison of forest productivity in Britain and Europe in relation to climatic factors.

4. Forest Ecology and Management 2:75-102

5. a. Finland, Great Britain, Norway, Sweden, U.S.S.R.

   b. Lodgepole pine, Norway spruce, Scots pine

   c. Climate/growth (direct relationships, latitude), Forest growth and yield

6. Based on yield tables, growth rates of Scots pine, lodgepole pine, Norway spruce and Sitka spruce were compared, and differences in growth in various countries were related to climatic factors.

In the first part of the article, broad comparisons were made between climatic types in Britain and in Europe and northwestern North America. The author stressed that climatic differences have not been studied in depth and the opinions offered were very tentative. Highlights of important climatic parameters are summarized below.

Comparisons were made between European areas with continental climates and those with maritime climate. A clinal growth pattern from extreme oceanity in western Ireland to extreme continentality in central U.S.S.R. was apparent. This gradient influences different species in varying intensity. For example, a predominantly continental species such as Scots pine grows extremely well in eastern Europe and U.S.S.R. but suffers frequent climatic damage when planted on the west coast of Great Britain. The aspect of oceanity most conducive to tree growth was suggested to be the long growing season rather than a high level of accumulated temperature.

There is a latitudinal temperature cline in the countries studied, with temperature increasing from north to south. In terms of growth, this north-south temperature gradient is partly compensated for by the longer day length during the middle of the growing season at higher latitudes. Temperature may be a significant factor only during the growing season but with evergreen coniferous trees there is the possibility of photosynthesis whenever the temperature rises above a threshold value, generally considered to be about 6° C.

The length of the frost-free season is of critical importance particularly with those species and provenances that are able to take advantage of a longer growing season.

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Christie, J.M. and R. Lines. 1979. Continued

The authors suggest that precipitation should be considered together with evapotranspiration, and seasonal distribution was suggested to be more important than total amount.

Patterns of height and volume growth of the four study species were very different over the range of countries compared. Much of the variation was believed to be due to climatic factors of which temperature, day length and moisture availability featured strongly. Wind is also of importance in Great Britain where it restricts height growth to a greater extent than in calmer regions. Winds also limit growth by causing windthrow before the economic rotation age has been reached.

The observed variation in forest productivity may be due directly to climatic effects or climatic/genotypic interactions, largely appearing as a latitudinal cline with increased growth at lower latitudes and generally better growth under the longer growing season of maritime climates. Other productivity variation, varying with species, was attributed to differences between provenances, soil factors, stocking or silvicultural treatment.

Studies of climatic suitability for Scots pine and Norway spruce forest production have been conducted over wide areas of the U.S.S.R. generally using indices based on evaporation, accumulated temperature above 10° C, and radiation balance.

1. CONKEY, Laura E.

2. 1979

3. Response of the tree-ring density to climate in Maine, U.S.A.

4. Tree-Ring Bulletin 39:29-38

5. a. Maine

   b. Spruce

   c. Climate/growth (direct relationships)

6. Dendroclimatic studies in the American Southwest have been successful in part because of the growth-limiting effects of low precipitation and high temperatures. There is thus a strong climate/growth relationship which is visible in the year-to-year variations in tree-ring widths. In contrast, the northeastern U.S. enjoys ample precipitation for most of the year, and temperatures are usually moderate in summer. Tree growth is more commonly limited in the northeastern U.S. by competition from surrounding trees for sunlight, moisture, and nutrients, and the tree growth/climate relationship is harder to establish. Thus, dendroclimatic studies using ring widths from eastern U.S. trees have been few, hampered largely by a lack of belief in correlations between climatic variables and tree-ring widths in humid regions.

Recent dendroclimatological studies in areas of ample moisture have included measurements of tree-ring density, as well as widths. Maximum (latewood) density values have been found by other researchers to be highly correlated with mean maximum August temperatures and runoff in Canada. The author tested this technique with red spruce, **Picea rubens**, from Maine, with density measured as g/cm^3.

In the case of spruce, maximum density is reached near the end of the growing season, and the break in density from one year to the next is an abrupt change from high to low values. The values of the yearly peaks of maximum density change from one year to the next, showing more variation than ring widths. This variation is remarkably constant from one tree to the next within each site, permitting much easier crossdating than with ring widths alone. Variation in density thereby represents a stronger signal of climate than do ring widths.

The results indicate that large rings are correlated with low temperatures in July, August and October of the previous year (an inverse relationship), and with high temperatures in December and January, and May, July and September of the current growing season (a direct relationship). Precipitation shows a significant correlation to growth only in the previous year.

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Conkey, L.E. 1979. Continued

The author expected to find that maximum density would be responsive to late growing season conditions since it occurs at the end of the yearly ring development and, indeed, there is a positive response to August and September precipitation. For red spruce, high maximum density occurred under hot, dry conditions in late summer, conditions probably related to water stress within the tree. The unfavourable water balance possibly discourages cell enlargement, and the photosynthates go instead into cell wall thickening. Other investigators in the Swiss Alps also reported a direct response of maximum density to summer temperature, but a somewhat weaker inverse response to precipitation in late summer than the author found in red spruce from Maine.

There are responses at other times of the year as well. A strong response is seen in May, positive to both temperature and precipitation. Maximum density is high when spring has been warm and wet, a different type of relationship than that seen in late summer. Maximum density is also inversely related to June temperatures of the previous year and to December and January precipitation, and directly to temperatures in February and April. These could represent various preconditioning phenomena.

The response functions of the total ring widths and maximum densities do not contradict one another in any monthly response. The widths integrate conditions over a larger time period and the densities have a more specific response: both together may be able to provide a more complete picture of past climate in northeastern parts of the U.S. than would be available from ring widths alone.

1. CRAGG, J.B., Alan CARTER, Clara LEISCHNER, E.B. PETERSON and G.N. SYKES

2. 1977

3. Litter fall and chemical cycling in an aspen (**Populus tremuloides**) woodland ecosystem in the Canadian Rockies.

4. Pedobiologia 17:428-443

5. a. Canada; Index map NM-11; Alberta; B.17

   b. Aspen

   c. Biomass (tree, shrub/herb)

6. In spite of the widespread occurrence of **Populus** species in coniferous and deciduous woodlands of the northern cold temperate zone, few estimates have been made of litter production. In the literature, different references to litter fall do not necessarily refer to comparable litter components. Very often, only leaf litter fall has been measured and, in some studies, estimates of total litter fall do not include input from large branches and stems. In this particular study, attention is given to all litter components from the above-ground parts of the over ory vegetation in an aspen woodland near the southwestern limits of the aspen grove section (50 02 N, 115 03 W). Reference is also made to above-ground input from the understory vegetation.

Small litter (leaves, twigs, pine needles, aspen and poplar reproductive parts and detritus) formed 74% of the total annual litter fall. Approximately 90% of the leaf fall occurred in October. Aspen leaves constituted 70% of the annual small litter fall. Twig input (15% of annual small litter) occurred mainly during the autumn and winter months and large litter fell mainly in the winter months. Mean small and large litter fall was 2,346 and 830 kg dry wt/ha/yr, respectively, while input from understory vegetation was approximately 1,030 kg/ha/yr.

The understory of the Kananaskis Valley aspen ecosystem had a dry weight biomass of 2,310 and 1,440 kg/ha in areas of open and closed canopies, respectively. Reproductive structures of the understory accounted for approximat· y 5% of the total litter fall. The dominant herbaceous plant, **Epilobium angustifolium**, contributed 375 kg/ha to litter input in 1974 and 1975. Based on late August samples an estimate of 980 kg/ha for litter input of herbs and dead parts of **Rosa** spp. was obtained in an area of closed canopy, close to the sites sampled in the present study. This figure is an underestimate for it includes litter contributions from only the dominant shrub, **Rosa** sp. Litter input from reproductive parts of the understory was estimated to have been 52 kg/ha.

Continued ...

Cragg, J.B., A. Carter, C. Leischner, E.B. Peterson and G.N. Sykes. 1977. Continued

Compared with other North American stands, estimates of leaf litter fall for the Kananaskis Valley stand are similar. The estimate for total above-ground litter fall from the overatory obtained in this study is greater than the average of 3.2 x 10^3 kg/ha/yr calculated by Bray and Gorham (1964) for deciduous woodlands in the northern hemisphere. However, the miscellaneous measurements summarized by Bray and Gorham in some cases did not include accurate estimates of large litter fall. The leaf litter figures summarized by Rodin, Bazilevich and co-workers include input from reproductive parts, seeds and small twigs as well as from leaves. It should also be noted that the figures for total litter fall reported by the Russian researchers include inputs from leaf litter, large branches and stems, underatory vegetation and dead roots. Estimates of total litter fall for 50 yr old aspen woodlands in the U.S.S.R. are very high, ranging up to 13.3 metric t/ha/yr (or 13.3 x 10^3 kg/ha/yr). Root residues accounted for approximately 11% of this figure.

1. CROPPER, John P. and Harold C. FRITTS

2. 1981

3. Tree-ring width chronologies from the North American Arctic.

4. Arctic and Alpine Research 13(3):245-260

5. a. Canada, Alaska; Index maps NO-19, NO-20, NM-20; Labrador, Quebec; B.32

   b. Larch, white spruce

   c. Climate/growth (direct relationships, latitude), Climatic change (dendrochronology, proxy data), Climatic variation (regional, temperature, precipitation), Treeline studies (climate)

6. Severe winters and prolonged droughts in the 1960's and 1970's have rekindled interest in climatic history for clues to future climatic variations and change. The Arctic has been shown to be an important sensitive climatic indicator as it has relatively large fluctuations in climate variables. To understand these fluctuations better, a long record of past climatic variability is desired. Unfortunately, climatic records back even to 1900 for the Arctic are rare, and so proxy records have to be utilized.

A literature search and an inspection of the Laboratory of Tree-Ring Research, University of Arizona, files revealed that over 100 tree-ring chronologies exist for the arctic region of North America. The indices for five unpublished chronologies are presented in this article and the various characteristics of 94 selected dendroclimatic chronologies are summarized. The autocorrelations, standard deviations, and mean sensitivities of the arctic chronologies are comparable to those for chronologies from eastern North America. Because of limited replication and chronology length, many of the arctic chronologies are of limited value for climatic analysis compared to those from lower latitudes. A surprising amount of basic data has already been collected but not fully analyzed for information on climate. The earliest published chronologies were developed primarily for archaeological dating control, with little concern for deducing past climatic variations.

The new chronologies reported here involved: western hemlock from Prince William Sound, Alaska (60 26 N, 147 45 W); white spruce from Spruce Creek, Yukon (68 33 N, 138 38 W); white spruce from Nain, Labrador (56 33 N, 62 00 W); white spruce from Border Beacon, Labrador (55 20 N, 63 15 W); and larch from Fort Chimo, Quebec (58 22 N, 68 23 W).

Response functions are an attempt to mathematically calibrate monthly climatic data with the annual ring-width indices of a final chronology using a multivariate procedure. The sign of the response function weight

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Cropper, J.P. and H.C. Fritts. 1981. Continued

for each monthly variable is an indication of the direction of the ring-width response to the particular climatic variable. There are a number of consistent features evident in the signs of the responses analyzed by the authors. The three eastern chronologies from Labrador and Quebec all show a direct response to temperature in the prior and concurrent June with an inverse response to temperature of the prior August. For precipitation the consistent positive responses are for precipitation in the prior June and November; and consistent negative responses are for prior July, prior December, concurrent January and concurrent April precipitation. For the Alaskan chronology the response to temperature is predominantly positive with a continuous positive response to temperature of the prior December through May. The response to precipitation is predominantly negative.

The responses of the Canadian chronologies confirm the results of Giddings (1940, 1943) and Oswalt (1960), in that the temperature in June is directly related to growth; however, it can be inversely related in August to the growth in the following year. Precipitation is most often inversely related to growth, although some direct relationships do appear.

1. CRUTZEN, Paul J., Leroy E. HEIDT, Joseph P. KRASNEC, Walter A. POLLOCK and Wolfgang SEILER

2. 1979

3. Biomass burning as a source of atmospheric gases CO, H_2, N_2O, NO, CH_3Cl and COS.

4. Nature 282:253-256

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels)

6. The potential importance of deforestation and biomass burning for the atmospheric CO_2 cycle has received much attention and caused some controversy. In this article the authors show the probable importance of biomass burning as a trace gas source, particularly CO, H_2, CH_4, N_2O, NO_x (NO and NO_2), COS and CH_3Cl. Some of these trace gases such as CO_2, N_2O and CH_4 contribute to the atmospheric greenhouse effect by their absorption of terrestrial thermal radiation.

The authors' estimates of areas annually burned, including wildfires in boreal forests, are listed in the table below, with the range shown for each activity.

Activity:	Total area burned and/or cleared (10^6 ha/yr)
Burning due to shifting agriculture	21-62
Deforestation due to population increase and colonization	8.8-15.1
Burning of savanna and bushland	600
Wildfires in temperate forests	3.0-5.0
Prescribed fires in temperate forests	2.0-3.0
Wildfires in boreal forests	1.0-1.5
Burning of industrial wood and fuel wood	-
Burning of agricultural wastes	-
TOTAL	630-690

Continued ...

Crutzen, P.J. et al. 1979. Continued

The ranges of estimates of the amount of dry weight biomass involved each year for each activity are as follows:

Activity:	Total biomass cleared	Annually burned biomass	Dead below-ground biomass	Dead unburned above-ground biomass
Burning due to shifting agriculture	31-92*	9-25	7-20	16-72
Deforestation due to population increase and colonization	20-33	5.5-8.8	4.0-8.0	10.5-16.0
Burning of savanna and bushland	-	4.8-19	8-16	2.4-4.8
Wildfires in temperate forests	10.5-17.5	1.5-2.6	2.8-4.7	6.2-10.2
Prescribed fires in temperate forests	1.2-1.8	0.1-0.2	0.6-0.9	0.2-0.3
Wildfires in boreal forests	2.5-3.8	0.4-0.6	0.7-1.1	1.4-2.1
Burning of industrial wood & fuel wood	31-32	10-11	5.5	1
Burning of agricultural wastes	-	17-21	27-31	1.9-2.3
TOTAL	130-250	48-88	56-87	40-109

* All units in this table are hundreds of terragrams (Tg) per year in which one Tg = 10^{12} g = 1 million metric tons; for example 31-92 in this table would be equivalent to a range of 31 x 10^{8} t to 92 x 10^{8} t.

Despite the limited amount of observations, the authors conclude that biomass burning, especially in the tropics where the rates of biomass production and biomass burning are unparalleled, has the potential to contribute in an important way to the global budgets of several major atmospheric trace gases. The authors also stress that tropical emissions occur in a photochemically very active and dynamically important region, in which substantial transfer of tropospheric air to the stratosphere takes place.

1. DIONNE, Jean-Claude
2. 1979
3. Radiocarbon dates on peat and tree remains from James Bay area, subarctic Quebec.
4. Canadian Journal of Forest Research 9:125-129
5. a. Canada; Index maps NN-18, NM-17, NM-18; Quebec; B.4, B.5, B.6
   b. Black spruce
   c. Climate/growth (indirect influences), Climatic change (hypotheses, proxy data)
6. This paper reports the results of ^{14}C dates from bogs in an area south of the James Bay lowlands in Quebec. The data indicate that after land emergence, forest occupation may have been delayed 300 to 1,500 yr, while paludification was delayed 700 to 2,100 yr. A delay ranging from 400 to 900 yr between forest occupation and the establishment of bog conditions was suggested by data from the study area.

The factors that caused the peat bogs to spread over the flat lowland surface are not known, although it is suggested that more humid conditions than at present were the cause. Other studies have indicated that during the last 2,350 yr the climate has cooled and become more humid. This change of climate very likely contributed to the establishment of the peatland conditions which favoured a forest composed chiefly of black spruce.

The author concluded that significant climatic changes cannot be deduced from these ^{14}C dates because peat deposition in bogs began at various dates that reflect geological events rather than climatic events.

1. DOLGIN, I.M.

2. 1970

3. Subarctic meteorology.

4. IN: Ecology of the Subarctic Region. Proceedings of the Helsinki Symposium. UNESCO, Paris. p. 41-61

5. a. U.S.S.R.

   b. Nil

   c. Climate (air masses, precipitation, temperature, insolation), Climate/growth (microclimate, latitude), Growing season (length, frosts)

6. In view of the great longitudinal extension of the Eurasian subarctic, the underlying surface and circulation conditions and related weather conditions differ widely. Therefore, the meteorological regime is considered in three individual areas in this article: the western area, which includes the territory as far east as Taimyr Peninsula; the central area covering the territory from Taimyr Peninsula to Kolyma; and the eastern area including Chukchi Peninsula and northeastern Siberia.

The subarctic is the zone of most frequent encounters between arctic air and air masses of temperate latitudes. That is the reason for the occurrence of the arctic front with different positions in summer and in winter. At the arctic front cyclonic activity of varying intensity develops. It is with the European sector that the occurrence and active development of cyclones is associated, and within the Asian sector the regeneration of the polar frontal cyclones in the subarctic region occurs more frequently.

For subarctic ecology, absorbed radiation, determined by the reflective power (albedo) of the underlying surface, is of primary importance. Annual values of absorbed radiation increase from 34 to 38 kcal/cm^2/yr as one moves from west to east along the northern boundary of the subarctic region and at the southern boundary from 37 to 46 kcal/cm^2/yr. Thus, the subarctic region utilizes little of the incoming heat and that is one of the main reasons for the severity of climate. The loss of heat by the underlying surface as a result of radiation is, on the average, about 32% of total radiation for the year.

The annual radiation balance for the whole of the subarctic is positive and amounts at the northern boundaries to 10 kcal/cm^2/yr in the west and 14 kcal/cm^2/yr in the east. At the southern boundaries from the central to the eastern areas it increases from 12 to 20 kcal/cm^2/yr.

In small areas under the influence of local factors, microclimatic features may be observed which differ from the climate of the whole region. For example, depending upon the nature of soil and plant cover,

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albedo can vary. Elements of radiation balance in the same region with different relief may change even more than albedo, especially when north-facing and south-facing slopes are compared. In June, with the sun's altitude of 40 to 46° at noon, slopes facing the sun and having an inclination of 45 to 50° receive 4 to 5 times more heat than received by a horizontal surface. It is known that vegetation behaves differently on slopes with different exposure. Differences in plant development phases may be from 5 to 18 days when north-facing and south-facing slopes are compared.

The field temperature in summer throughout the whole of the subarctic is more homogeneous than in winter. The diminution of circulation intensity in summer leads to a decrease of diurnal temperature change. A sharp temperature drop of 4 to 6° C in July occurs near the shores of cold seas, where the horizontal temperature gradient, in places, amounts to 6 to 10° C/100 km. Local relief has an influence upon duration of the frost-free period. In the area of Yugor and Taimyr peninsulas, in convex topographic forms, it increases by 20 days in comparison with its duration on level terrain.

One of the most characteristic features of the thermal regime of the subarctic is the existence of temperature inversions throughout most of the year. Inversions, to a considerable extent, determine the nature of the earth's surface radiation, cloudiness and precipitation. It is known that the upper boundary of the surface inversion coincides with the lower boundary of lower clouds and that steady fogs are associated with the inversion. The most frequent recurrence of surface inversions throughout the whole of the U.S.S.R. subarctic region occurs in February and March. Over the western area, days with inversions amount to 40 to 60% of the period, and over the central and eastern areas from 60 to 90%. By July the recurrence of surface inversions diminishes to a level of 10 to 20%.

Owing to frequent non-intensive precipitation, high relative humidity and low air temperature, evaporation in the subarctic is slight. In the northern part of the central area, less than 50 mm of moisture evaporates over the course of a year; to the west, east and south, evaporation increases and in the southern part of the western subarctic reaches its highest value of 150 to 200 mm/yr. Thus, in the subarctic, precipitation exceeds evaporation and results in surplus wetting of grounds. The most intense evaporation is observed in July when 20 to 30% of total annual evaporation occurs.

The author indicated that in eastern Siberia there has been a warming of climate in the 20 yr from 1950 to 1970, in contrast to a slight cooling in Alaska, indicating that climatic changes in this period are not the same in the whole of the subarctic.

1. BOLGUSHIN, I. Yu.

2. 1969

3. The effect of climatic fluctuation on the physical environment and conditions of economic development of the middle Ob' district.

4. Izvestiya Akademii Nauk SSR, seriya geograficheskaya, 1968, No. 5. p. 69-83

5. a. U.S.S.R.

   b. Nil

   c. Climate/growth (indirect relationships), Climatic variation (precipitation)

6. The study area, centered on the settlement of Vostykhoy 100 km northwest of Khanty-Mansiysk, covered a section of land on the left bank of the Ob' River between the floodplain and the drainage divide of the Seul' River. The area is part of the middle taiga subzone. The author's data suggest a definite relationship between the formation of peat bogs and climatic fluctuation. The period of accumulation of the horizon of heavily decomposed peat appeared to correspond to a previous period of warming and increased aridity. The intermediate layer accumulated in the period of gradual moisture increase, and the overlying peat layers, with evidence of periodic flooding, originated in a later period when there were peaks of precipitation.

The growth curves of many trees examined by the author exhibited a close correlation with intrasecular climatic fluctuation. Oddly, tree growth in several habitats, especially at the beginning and in the middle of wet periods, was directly proportional to precipitation and had little relationship to temperature. At first glance, such a relationship may seem paradoxical in an area of excess moisture and insufficient heat. One explanation is that most of the trees in the study area suffer either from oxygen insufficiency in soil moisture or from a shortage of nutrients. In wet periods, especially if the amount and frequency of precipitation increases in June and July, the situation changes fundamentally. Precipitation carries both oxygen and nutrients into the soil. In wet periods, when the general moisture supply of an area is on the increase, the more highly mineralized waters are extruded from the subsoil toward the surface. This phenomenon is undoubtedly promoted by the process of diffusion, in which the precipitated moisture becomes saturated with chemicals ascending from the ground water. At the same time surface runoff increases, carrying a greater amount of nutrients and oxygen over every portion of the surface per unit of time, and this, as a general rule, tends to promote the functioning of root systems. As a result, there can be a temporary beneficial effect of periodic wet periods for tree growth. However, any such improvement lasts only until a rise in the water table reaches a certain limit; thereafter, a substantial number of trees will die.

1. DOUCET Rene, John V. BERGLUND and Eugene FARNSWORTH

2. 1976

3. Dry matter production in 40-year-old Pinus banksiana stands in Quebec.

4. Canadian Journal of Forest Research 6:357-367

5. a. Canada; Index map NL-18; Quebec; B.7

   b. Jack pine

   c. Biomass (tree)

6. Dry matter production data were obtained for jack pine (Pinus banksiana Lamb.) stands growing at three density levels on two sites in Quebec approximately 150 km northwest of Trois Rivières (47 05 N, 73 30 W). Regression equations relating tree weight to diameter and height were calculated for stem wood, stem bark, branches, needles, cones, and total above-ground biomass, as well as for periodic net annual increment of these components. Different sets of equations were needed to evaluate biomass on each site, but density levels within sites could be grouped. Total net periodic annual weight increment was linearly related to foliage weight and basal area, but a leveling-off at higher densities was evident when basal area was replaced by stand density index or bole area equivalent as the measure of density.

Total biomass per unit area fell within 10% of the values found by Hegyi (1972) for stands of about the same age and density in Ontario. However, total periodic annual production was considerably less than that of communities described by Baskerville (1965). Apart from differences in species and location the authors suggested that maximum production in species like jack pine may be attained at a relatively young age and may decrease significantly in stands approaching 50 yr. In this study, both diameter and height growth had declined in the last few years.

For each site there was a marked drop of total biomass at lower densities, and the relationship between total standing crop and basal area was linear. From 60 to over 70% of total standing crop was accounted for by stem wood, the lower percentage being found on th. medium site. The amount of foliage per hectare was also closely related to basal area and the relationship is again linear; it was higher on the medium site, both in absolute value and in percentage.

Continued ...

The distribution of above-ground standing crop, dry weight (kg/ha), by site index and density class was as follows:

Site	Density class	Above-ground standing crop, dry (kg/ha)
Good	High	102,548
Good	High	106,393
Good	Medium	99,344
Good	Medium	102,538
Good	Low	62,880
Good	Low	74,798
Medium	High	95,520
Medium	High	98,202
Medium	Medium	79,812
Medium	Medium	88,414
Medium	Low	64,492
Medium	Low	60,897

The distribution of the above-ground net periodic annual increment, dry weight (kg/ha/yr), by site index and density class was as follows:

Site	Density class	Above-ground net period annual increment, dry (kg/ha/yr)
Good	High	4,608
Good	High	4,692
Good	Medium	4,612
Good	Medium	4,670
Good	Low	3,001
Good	Low	3,446
Medium	High	5,464
Medium	High	5,498
Medium	Medium	4,758
Medium	Medium	5,173
Medium	Low	4,036
Medium	Low	3,847

Total increment was proportional to the amount of foliage and for a given amount of foliage, total annual production was higher on the good site. In other words, average crown efficiency was 0.94 for the good site and 0.71 for the medium site, but this was not enough to compensate for the smaller amount of foliage found on the good site. Examination of individual trees also showed that crown efficiency increases with decreasing stem size and that it was always higher on the good site, except for very small stems.

Continued ...

The fact that the medium site was more productive than the good site seems to invalidate the use of site index as a measure of site quality. Other site characteristics supported the classification given by site index; for example, the medium site had a poorer ground flora in terms of number of species. The presence of a discontinuous iron pan was noted on the medium site and this factor is known to adversely affect height growth of jack pine. In this study, site index failed to classify site adequately in terms of current productivity. Site index is dependent on height from stand establishment to the time of measurement and does not necessarily reflect current productive capacity. Moreover, measurement of current production is subject to error and this must be taken into account when differences in site index are not very large, though site index may still be adequate for classifying forest land into broad classes of productivity.

Trees of a given diameter and height in stands of the same age, but of different site indices, are not in the same position of dominance. Consequently, regression equations relating tree weight to height and diameter at breast height must take site into account when precise estimates of biomass increment are needed.

1. **DREW, James V. and Royal E. SHANKS**

2. 1965

3. Landscape relationships of soils and vegetation in the forest-tundra ecotone, upper Firth River valley, Alaska-Canada.

4. Ecological Monographs 35:285-306

5. a. Alaska, Canada; Index map NR-7/8/9; Yukon; B.33

   b. White spruce

   c. Climate/growth (direct relationships, microclimate, latitude), Treeline studies (growth, climate)

6. This paper describes a study of relationships between soils and vegetation in the upper Firth River valley basin, near the Alaska-Canada boundary. The white spruce stands in the study area represent a northern extension of tree-form conifers into the tundra. Various factors of climate, topography, soil conditions and Pleistocene glaciation were considered as important in controlling the northern limits of spruce.

Insufficient precipitation has been suggested as a possible factor limiting tree growth in the Canadian northwest, although much of this area is underlain by permafrost that restricts drainage and allows soils to remain in a moist condition during the growing season in spite of low precipitation. In the upper Firth River valley, insufficient precipitation did not appear to be a limiting factor in the survival of spruce on soils that thaw sufficiently and have a suitable moisture holding capacity.

Mid summer temperature has been suggested as a major control in the location of treeline. In the absence of climatological data, this could not be directly confirmed in the Firth River study area. The authors speculated that prevailing southerly winds may allow warm summer temperatures from the interior of Alaska and Canada to prevail further northward down the Firth River valley than one would expect for that latitude.

The tendency toward restriction of spruce to sheltered valleys near its northern limits suggests that protection from desiccating winter winds is important in survival at these latitudes. Although the Firth River valley may provide some protection, several lines of evidence point to strong winter winds in the valley itself. Many spruce trees in open areas have bare stem areas due to abrasion by wind-borne ice and snow at the winter snow surface.

The authors suggest that there is a possibility that the northern occurrence of spruce in the Firth River valley represents a relict of previous vegetation that was obliterated in surrounding areas by Pleistocene glaciation.

Continued ...

The direction of site exposure (aspect) and soil conditions are critical in the survival of spruce. Soils of south-facing slopes, and moderately fine textured soils underlain by gravel at positions near terrace edges or adjacent to streams, provide sites where white spruce survives.

Several lines of evidence indicated that the spruce stands were neither advancing nor retreating. Aerial observations indicated that the occurrence of spruce stands at the time of this study corresponded to the location of conifer stands depicted on the International Boundary Survey Map of the area based on measurements made in 1911 and 1912. A stable altitudinal treeline was indicated on a slope in the study area where spruce clumps became more widely spaced in an upslope direction, but there was no evidence of dead trees at elevations above the living trees. The white spruce trees on the river terraces were at least 250 yr of age and showed no indication of replacement or stand degeneration.

1. DROZDOV, A.V.

2. 1971

3. The productivity of zonal terrestrial plant communities and the moisture and heat parameters of an area.

4. Soviet Geography 12:54-60

5. a. U.S.S.R.

   b. Spruce, birch

   c. Biomass (tree, shrub/herb, moss/lichen), Climate/growth (direct relationships)

6. This paper presents suggested refinements of the Grigor'yev-Budyko findings on the relationship between heat and moisture parameters and the productivity of plant communities. To estimate the effect of heat and moisture on the zonal distribution of plant production, the author used the annual magnitudes of the radiation balance 'R' (expressed in kcal/cm^2/yr) and the radiation index of dryness, designated by R/Lr, where Lr is the amount of heat needed to evaporate the annual sum of precipitation. Precipitation is expressed as 'r' and 'L' is the latent heat of phase transitions.

The following propositions were made by Grigor'yev and Budyko: 1) the productivity of plant communities reaches a maximum at some optimal value of R/Lr close to 1, and declines for a constant R on both sides of the optimum as the values of the R/Lr ratio change; 2) for an optimal R/Lr ratio, productivity will increase with the absolute values of the magnitude in the ratio. When the formula was originally proposed biomass data were lacking for other plant communities outside the U.S.S.R. and for the total growth of vegetation including the below-ground portions.

The present author notes some disadvantages of the climatic parameters used in the formula R/Lr. A dryness index greater than 1 suggests a surplus of heat and an inadequate moisture supply. Index values below 1 indicate excess moisture. These relationships hold true, and various parts of the world can be compared in terms of the dryness index, provided that the compared territories are large enough and sufficiently homogenous in relief, and provided the index is based on long-term average data. However, even long-term averages do not adequately reflect seasonal aspects of climate. For example, a given annual sum of precipitation may have quite different seasonal distributions in various regions. In such situations, the dryness index of these regions (assuming identical R) would be the same while the seasonal magnitudes of R/Lr would very widely. The seasonal patterns may produce significant differences in the productivity of the regions, so that different amounts of production would correspond to identical values of the dryness index.

Continued ...

The author's productivity estimates, for above-ground and below-ground components combined, are listed below for subdivisions of the boreal forest within the U.S.S.R. in relation to radiation balance, R, and the radiation index of dryness, R/Lr.

Plant community	Annual growth (t/ha/yr)	R	R/Lr
Spruce-green moss (northern taiga)	5.6	23.5	0.74
Spruce-bilbery (northern taiga)	6.5	25.0	0.82
Spruce-green moss (nothern taiga)	6.0	25.0	0.83
Spruce-bilberry, spruce-grass-green moss (middle taiga)	6.0	29.5	0.82
Spruce-green moss (middle taiga)	7.9	28.0	0.73
Spruce-green moss, spruce complex, mixed forest (middle taiga)	9.0	33.0	0.75
Birch forest, grassy	11.1	33.0	0.76

The heat factor operates in a single direction with plant productivity increasing as R rises. However, the rate of plant growth tends to vary for different values of R within the dryness index interval of 0.4 to 1.4: at the low values of R, the addition of heat produces a rapid relative increase of production but in a warm situation the same heat increment produces a smaller relative increase in growth. At values of the radiation balance below 40 kcal/cm^2/yr, productivity increases rapidly with the additional application of heat. But at higher values of R (above 50 kcal/cm^2/yr), moisture is the predominant factor in increasing plant productivity; this is especially noticeable as the dryness index declines below 1.

After comparison of several plant communities in relation to the R/Lr index, the author concluded that a decline in the dryness index towards excess moisture (down to the value 0.5) at high values of R (in excess of 40 kcal/cm^2/yr) results in a significant increase in plant production. This would mean that a dryness index equal or close to 1 is not necessarily optimal for plant growth in all thermal belts.

1. EDDY, John A.

2. 1977

3. Climate and the changing sun.

4. Climatic Change 1:173-190

5. a. Northern hemisphere

   b. Mil

   c. Climatic change (hypotheses, dendrochronology, proxy data), Climatic variation (temporal, temperature)

6. Almost all efforts to identify a sun-weather connection have concentrated on short-term changes, and have focused on the cyclic behaviour of solar activity that is most easily observed as daily changes in the numbers of spots on the sun, and the 11-yr sunspot cycle. With this restriction we may have overlooked other regimes of solar change that could be more fundamental both in solar and in terrestrial response. In studying climatic change, in particular, one is obliged to consider the possibility of solar variation of terms longer than 11 yr. The existence of longer-term changes is apparent in the sunspot numbers record that extends for over 350 yr and thus embraces periods of marked terrestrial climate change. The amplitudes achieved at 11 yr maxima in the curve of annual sunspot numbers are far from uniform. There is an apparent 80-yr cycle, called the 'Gleissberg cycle', and other longer-term anomalies. Sunspots and related solar activity seem to have fallen to near-zero levels during a period in the late 17th and early 18th centuries known as the Maunder Minimum.

Several lines of evidence now suggest that varying solar activity may directly record long-term excursions in the solar radiative flux. The persistent rise in the level of solar activity in the first half of the present century matches very well the established increase in world temperature averages during the same time. The Maunder Minimum coincides in time and extent with the coldest extreme of the Little Ice Age in western Europe and America.

In interpreting the tree-ring record for evidence of changes in solar activity, allowance must be made for several important effects. Of fundamental importance is an appreciable delay in the atmospheric reservoir between instantaneous changes in ^{14}C production in the upper atmosphere and resultant ^{14}C abundance variations in the biosphere. This lag is on the order of 10 to 50 yr. It tends to obscure short-term changes such as the 11-yr solar cycle, and to displace all effects in time. Thus, one finds the Maunder Minimum (A.D. 1645 to 1715) in tree rings formed somewhat later than the historically established time of the real drop in solar activity and aurorae.

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Whenever a dip in solar activity occurs the climate becomes colder and mid-latitude glaciers advance. When a prolonged maximum of solar activity is indicated glaciers retreat and the earth warms. The physical connection with long-term solar changes could be through the recognized increase in ultraviolet solar flux with solar activity, and the effect of that increase on chemical processes in the upper atmosphere. Were that the case, however, one should probably expect more obvious correlation of shorter-term solar activity and weather. The connection could also come about through known changes in the particle flux from the sun, as in the sector structure or high-speed streams of the solar wind, through some triggered reaction necessary to amplify the wholly inadequate energies in these fluxes.

The author's examination of solar history in fossil radiocarbon presents a rather compelling case for a direct connection between the sun and climatic changes of century or half-century time scales. Throughout the last seven millenia, extended periods of suppressed solar activity seem to coincide with times of protracted cold and mid-latitude glacier advance. Long-term highs in the level of solar activity are coincident with times of warmer climate and glacier retreat, as during the last several hundred years. The author suggests as a first hypothesis that both changes in solar activity and changes in climate result from long-term fluctuations of about 1% in the solar constant; such fluctuations come and go in a possibly aperiodic manner in time scales of centuries. A longer cycle of about 2,500 yr, made up of clustered maxima and minima, also appears in the radiocarbon record.

The weakest link in the chain of evidence is the climate record. One should also question the reliability of tree-ring radiocarbon as a real indicator of solar activity. The good agreement of radiocarbon-derived solar history with climate extremes raises the question of whether it is climate itself that is modulating radiocarbon levels in the tropospheric and oceanic reservoirs, with no important influence from the sun. Ocean and atmospheric temperatures can be expected to have an effect on the radiocarbon abundance in the biosphere, and that effect is probably not well established, although present models suggest that the solar modulation should be the more dominant influence.

If the sun changes in ways that affect world climate, high scientific priority needs to be given to monitoring of solar behaviour. The author stressed the importance of determining whether and how the radiative flux from the sun changes, and in what time scales. To determine whether the solar constant is varying, as implied by the author, requires long-term monitoring of both the bulk solar radiation and its terrestrially-important spectral components. This assignment is not an easy one, for it demands a capability of sensing changes of no more than 0.1% in a decade, carried out over many decades.

1. EGGINTON, P.A.

2. 1980

3. Determining river ice frequency from the tree record.

4. Geological Survey of Canada, Paper 80-1A:265-270

5. a. Canada; Index maps NQ-9/10/11/12, NP-9/10; District of Mackenzie; B.23a

   b. Nil

   c. Climate/growth (indirect influences), Climatic change (dendrochronology, proxy data)

6. At some locations between Fort Simpson and Norman Wells where bank slopes are moderate, trees along the Mackenzie River increase in size and age with elevation above the river. The limiting factor for tree age is the thrusting of ice blocks onto shore during breakup, thereby destroying existing trees. Uprooted trees up to 100 yr of age have been observed. The trees can provide a measure of frequency of ice events at a given location. At the relatively sheltered sites studied, ice movement on shore to elevations in excess of a few metres was associated with backwater. Even in these cases, however, ice was thrust to varying elevations. Observations at Fort Simpson indicate that even in sheltered sites where the main flow of the river and ice is away from a given bank, ice can still be thrust onto that bank to a considerable elevation as a result of a spring flood.

The Mackenzie River may be somewhat unique in that ice thickness, ice quantity, and breakup characteristics are such that ice can dominate the successional seres on the lower bank. Other rivers that experience a different breakup regime may not exhibit the same degree of ice control of tree age as does the Mackenzie River.

1. EKLUND, B.

2. 1956

3. Variations in the widths of the annual rings in pine and spruce due to climatic conditions in northern Sweden during the years 1900-1944.

4. Tree-ring Bulletin 21:21-24

5. a. Sweden

   b. Scots pine, Norway spruce

   c. Climate/growth (direct relationships, latitude), Climatic variation (temporal, temperature)

6. The annual growth ring index of pine showed a pronounced variation between 1900 and 1944 which indicated that climate exercised a very noticeable effect on annual ring formation. Climatic conditions of the preceding year had a very marked effect on the annual rings of pine, probably due to changes in the amount of foliage. Narrow rings in periods of good climatic conditions were believed due to the loss of material to flower and cone production at the expense of radial growth.

The pronounced variation of the pine growth rings was not evident in spruce data. The author suggested that within a wide geographical area the growth climate was probably recorded in a more uniform manner in the annual rings of the pine. The harsher the climatic conditions under which the annual ring formation takes place, the more strongly accentuated will be the record of extremely good or poor years. Better correlations between climate and ring data were found from the more northerly locations of this study. The further north data were obtained, the more markedly the annual ring formation of pine appears to be dependent upon the weather conditions during the year prior to formation of the ring. Data from spruce obtained from progressively more northern locations also seem to be influenced by weather conditions of the year preceding ring formation. However, the tendency was not as pronounced or as statistically reliable for the spruce data as it was for pine.

A comparison was made of the annual ring index series for the climatic regions in northern Sweden distinguished by Angstrom as 'local continental' and 'local maritime'. The analysis indicated that climate affected the annual ring variations in all areas in a relatively uniform manner.

Tree ring data were also separated into four altitude classes and this indicated that the annual ring variations run relatively synchronously at all altitudes. Using the age and average height of the stand the data were separated into five site class groups. Although the absolute ring width varied by site classes, variation in annual ring width was independent of the site class for both pine and spruce.

Continued ...

Eklund, B. 1956. Continued

Density of the timber stand did not exercise any influence on the variation of the annual ring width due to climatic conditions in either pine or spruce. Climatic moisture differences had an apparently slight effect on annual growth ring variations. This supports the view that in northern Sweden temperature conditions during the vegetative period, and probably during the most intensive phases of the growth period, are responsible for the annual variations in the growth rings of spruce. However, in the case of Scots pine consideration also has to be given to the fact that temperature conditions not only exercise an influence during the growing period but tree growth is also influenced by weather conditions from the preceding year.

The author made a special effort to determine the possible climatic fluctuations recorded in the data. Growing season conditions remained substantially unchanged during the period of this study. The changes in average yearly temperatures were due to a rise in the winter temperatures during the study period. The author concluded that the statistical methods available were not significantly developed to enable the successful isolation of any long term climatic effect from the complex of site and stand influences recorded in the annual rings of conifers.

The author concluded that the radial growth of both pine and spruce is characterized by such a marked variation due to climatic conditions that it must be taken into account in forestry calculations. It was also stressed that to obtain reliable annual ring indexes both for research work and for practical forestry it may be necessary to prepare and carry on a continuous investigation of the annual ring development in specially selected undisturbed stands which are known as "indicator stands".

1. ELKINGTON, T.T. and B.M.G. JONES

2. 1974

3. Biomass and primary productivity of birch (**Betula pubescens** S. Lat.) in south-west Greenland.

4. Journal of Ecology 62:821-830

5. a. Greenland

   b. Birch

   c. Biomass (tree), Treeline studies (growth)

6. Measurements of biomass and estimates of net primary productivity were made on a stand of birch (**Betula pubescens**) at Eqaluit Bay, (61 06 N, 45 58 W) in southwestern Greenland, about 30 to 40 km south of the northern limit of the species. It forms scrub-woodland approximately 2.5 m high on sheltered slopes. Individual trees lack trunks as their branches ascend from a horizontal stem or 'caudex'.

Total dry weight biomass was estimated at 54.9 t/ha, with 1.2 t/ha in leaves, 35.8 t/ha in branch wood and bark, 11.4 t/ha in caudices and 6.4 t/ha in roots. Net primary productivity of above-ground parts was estimated at 1.98 t/ha/yr with only 0.64 in the branch wood and bark and 0.15 in the caudices, compared with 1.20 t/ha/yr in the leaves. Leaf area index was 1.57 m^2/m^2. Net primary productivity of roots was estimated at 0.09 t/ha/yr.

It is clear that the biomass (per tree and per area) and productivity of birch in Greenland are lower than those of temperate birch woodland, which in turn has the lowest biomass (63.4 t/ha) of the forest types compared by Ovington (1965). Total net primary productivity in the Greenland stand (2.1 t/ha/yr) is also low when compared with the lowest figure given by Rodin and Bazilevich (1967) for corrected net primary productivity in forests, which is 3 t/ha/yr for northern taiga fir forest. Whereas measurements of net productivity made in temperate regions on birch, beech and spruce have shown the productivity of leaf material to be much less than that of branches, the reverse is found in the Greenland stand. In English birch, leaf material accounts for about 18% of the productivity of above-ground parts, whereas the comparable figure for Greenland is about 60%. Under the growing conditions in Greenland, leaf production is one of the major sinks for photosynthates synthesized in the previous year and only very low growth rates for wood are possible. The morphological consequence of this situation is that the branches appear densely leafy because the spur shoots, on which the majority of leaves are borne, are closer together than on trees from temperate regions.

1. ELLIOTT, Deborah L.

2. 1979

3. The current regenerative capacity of the northern Canadian trees, Keewatin, N.W.T., Canada: some preliminary observations.

4. Arctic and Alpine Research 11:243-251

5. a. Canada; Index map NP-13/14; District of Keewatin, District of Mackenzie; B.27, B.32

   b. Black spruce, Larch, White spruce

   c. Climate/growth (latitude), Climatic variation (temporal), Treeline studies (growth, climate)

6. There has been speculation that the northernmost tree outliers are relicts of the Hypsithermal treeline, which was further north until approximately 3500 B.P. To further test the hypothesis that today's northernmost trees are historical relicts, the author documented the stability and current regenerative capacity of trees in a 140-km transect of nine study sites that crossed treeline from the south end of Kasba Lake to the north end of Ennadai Lake in the Northwest Territories. If the northernmost trees are not sexually reproducing today, this could explain some of the incongruities between treeline and certain climatic parameters, such as the 10° C isotherm and the mean summer position of the arctic front, which have been suggested to be determinants of the northern treeline.

The author noted that the general absence of juvenile trees in the forest-tundra ecotone corresponds to a global cooling since the 1940's. The minor warming of 0.5 to 0.6° C from 1880 to 1940 was apparently of insufficient magnitude to encourage sexual reproduction in most of the ecotonal tree stands, though verification of this statement awaits the completion of dendrochronological studies. Palynological and paleosol studies in Keewatin have shown that treeline was at least 280 km north of its present position for at least part of the Hypsithermal. The ecotonal stands that were once part of this northern forest were left on favourable sites; these stands have continued to survive in the ecotone because of their ability to vegetatively reproduce, with the warm summer temperatures necessary for sexual reproduction not being required. The author considers the northernmost trees in Keewatin to be in a perilous situation, either in retreat or barely maintaining their position through asexual reproduction. In contrast, the northernmost trees in Labrador-Ungava are in a healthier condition, with abundant sexual reproduction.

This study included the use of tree-ring analyses to determine age structure and years of optimum growth for black spruce, white spruce and larch, but these data are not included or discussed in the author's report.

1. ERONEN, Matti

2. 1979

3. The retreat of pine forest in Finnish Lapland since the Holocene climatic optimum: a general discussion with radiocarbon evidence from subfossil pines.

4. Fennia 157:93-114

5. a. Finland

   b. Scots pine

   c. Climate/growth (indirect influences, latitude), Climatic change (hypotheses, proxy data), Treeline studies (climate)

6. Included in this paper is a discussion of ecological factors tending to restrict the distribution of Scots pine in Finnish Lapland. Particularly where trees occur as isolated individuals, winds may inflict considerable damage. Trees may be blown down in storms, or injured as young saplings and permanently deformed. Only on a few occasions in any century do pines in the northernmost forest produce viable seed. This, together with the fact that more than 100 yr are needed for a tree to reach a mature condition, implies a slow rate of regeneration that allows storm damage to exercise a much greater impact upon the northern forests than those of southern Finland. Pine forests that have been destroyed by storms are visible in many parts of Finland. It is also possible that wind strengths in general have increased since the end of the Little Ice Age, which occurred between 1550 and 1850 A.D.

No fire scars were found on the subfossil tree trunks used for this study, which dated back to 7000 B.P. This suggests that forest fires were not common in the northern treeline zone in past millenia. The author cautions that most of the samples came from damp environments and would have been protected from most fires. However, the author suggests that forest fires were not of any major significance as a cause of the retreat of the limit of pine forests in past ages. Only the relatively recent fires due to activities of man are thought to have had a strong influence on this retreat.

The pine forest limit and tree limit both decrease in altitude from the south to the north, so that in the southern part of the mountains of Scandinavia pine will grow at an altitude of about 1,000 m above sea level. The period of uplift immediately following glaciation was extremely rapid in Scandinavia, with rises of 40 to 50 m calculated in relation to sea level during the first 2,000 yr following glaciation in spite of a simultaneous rise in sea level. Therefore, land uplift may have played some part in the environmental changes that have taken place in northern Lapland since the last glacial period. The direct influence of this process on local climatic conditions since the postglacial

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climatic optimum will have been small as current observations suggest that air temperature decreases only by approximately 0.5° C for every additional 100 m altitude above sea level. The effect of uplift may be in shifts to a more continental climate, and changes in air mass patterns due to the increasing height of the mountains in Scandinavia.

The principle reason for retreat in the limit of pine in northern Finland has been the general deterioration of climate, one factor in which will have been land uplift. The cooling in mean temperature since the postglacial climatic optimum has been estimated to be in the order of 2° C in southern Finland, while the estimated decline in summer temperatures in the mountain areas of Scandinavia are in the range of 1.5 to 3.5° C, based on the lowering of the altitudinal limit of Scots pine.

Conflicting information is available concerning variations in precipitation since the last glaciation, although it has been proposed that the warm Atlantic period was also a relatively humid one. If precipitation has declined since the climatic optimum this may have exercised a local influence on the forests close to the forest limit. However, since the climate is relatively humid, the variations in precipitation levels which may have taken place are unlikely to have played a critical role in the changing environment at the forest limit.

Pollen analysis indicates that the retreat in the forest limit has in general been an even process over a wide area of Lapland, with the same trend continuing for several thousands of years. However, the process is unlikely to have been linear for there were doubtless periods of more and less favourable climatic conditions. With data and methods presently available it was not possible to trace any periodicity to the climatic fluctuations.

In summary, the author concluded that low temperatures restrict growth of Scots pine and in many places wind may also be a highly significant ecological force, for there are some places where repeated storms may prove a barrier to long-term pine growth. The 'thinning' effect of occasional storms throughout the area around the forest limit is also emphasized. This effect is forced by the fact that the rate of forest regeneration is very slow. Further, there are parts of northern Lapland where the soils are so poor that this factor serves to prevent the growth of pine forest locally. Precipitation is hardly ever a minimum factor for forest growth in Lapland.

The principal reason put forward by the author for retreat of the northern treeline is a decline in temperatures over the last few thousand years. Within Fennoscandia this trend may have been further compounded by the effects of land uplift, even if the extent of the latter is difficult to assess in the presence of the former global effect. This

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general climatic deterioration may also have brought about changes in annual weather conditions, and in this way the changes brought about by land uplift may be overshadowed by other variations.

It remains unknown, however, what part movements in the earth's crust may have played in climatic deterioration since the last glaciation. The areas of northern Europe and North America which were once under ice have risen a considerable amount during the postglacial period, but land uplift has also been detected elsewhere, presumably associated in part with continental drift and the folding of mountain ranges. In any event, land uplift in any part of the world, whatever its cause, is bound to have some effect on local climate in the course of several thousand years, and in this way land uplift may also come to play a considerable role in climatic deterioration on a world scale.

Human activity may have caused some retreat in the northern treeline in Fennoscandia in recent centuries. In spite of the fact that quite abrupt changes in environmental conditions have occurred at the forest limit in recent decades, the trends that have given rise to retreat in the limit of pine forest began well before there was any visible human activity in Lapland, some 5,000 yr ago.

1. FAHNESTOCK, George R.

2. 1979

3. Carbon input to the atmosphere from forest fires.

4. Science 204:209-210

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels)

6. It has been estimated by Wong (1978) that forest fires and land-clearing fires release 5.7×10^{15} g of carbon/yr into the atmosphere. Natural sinks remove most of this but 1.5×10^{15} g of carbon/yr, almost exclusively due to new tropical clearing, constitutes 22% of the net input from all anthropogenic sources. However, these calculations of the consumption of organic matter have been made by applying a combustion efficiency of 0.75, derived from experimental burning of felled and partly dried logging debris, to total living phytomass, little of which burns. The result is that there have been overestimates by a factor of about 7 of gross carbon input from fires in the temperate and boreal zone. If, as seems likely, estimates for the tropics are similarly exaggerated, the net carbon input from forest burning is much less significant than estimated by Wong (1978).

Estimates of the mean consumption of living and dead organic matter by wildfires is 2.46×10^3 g/m^2 for Alaska. This mean includes boreal forest and nonforest. The gross yield of carbon, calculated at 45% of the total dry matter reduced by 7.5% of unburned particulates, is 0.97×10^3 g/m^2. For the temperate and boreal area burned annually worldwide, the gross carbon input is 0.11×10^{15} g/yr, as compared with Wong's estimate of 0.47×10^{15} g/yr.

1. FLOWER-ELLIS, J.G.K. and H. PERSSON

2. 1980

3. Investigation of structural properties and dynamics of Scots pine stands.

4. IN: T. Persson, Editor, Structure and function of northern coniferous forests - an ecosystem study, Ecological Bulletins (Stockholm) 32:125-138

5. a. Sweden

   b. Scots pine

   c. Biomass (tree, shrub/herb)

6. The studies of biomass distribution and structure may be divided into two parts: those concerned with the structure of the stands at a given moment which is a static description, and those concerned with the rate and direction of change within them. The second of these may be further subdivided into those studies describing the instantaneous rate of change, such as leading shoot and diameter growth, and those reconstructing the historical events of growth leading to the status of a stand at a given moment. The structural description of a stand at a moment in time is a prerequisite to the description of most processes in the stand; for example, mineral nutrient fluxes must be related to the total amounts present in the system. The tree stand, as the dominating component of the forest ecosystem, may appear to be the natural unit for which changes are to be expressed, but many of the most important processes involved in the modelling of the functioning of the ecosystem cannot be studied at stand level.

The studies of structure and growth in the Swedish Coniferous Forest Project (SWECON) were designed to be applicable at three levels: 1) organ level (needle, shoot); 2) tree level; and 3) stand level, all within the context of an age sequence of stands.

One of the most striking features of conifers, and indeed of many evergreen plants, including the dwarf shrubs of the field-layer, is the extent to which the needles or leaves are utilized as storage organs for carbohydrates. This function gives rise to substantial (16 to 28% of dry weight) variation in the unit weight of a needle during the year, and, to a lesser extent, that of shoots. Thus the weight increment of a shoot during the year was measured in terms of the increase in its weight per unit length per unit time. Similarly, roots of different size classes were processed in such a way that not only dry weight, but also length, weight per unit length and volume would be available. These data, in combination with studies of reserve substances, indicated how the tree allocated its fixed carbon, both above and below ground. Study of other processes in the stand, such as litrerfall, were also expressed in terms of the numbers and unit weights of organs per unit time.

Continued ...

Flower-Ellis, J.G.K. and H. Persson. 1980. Continued

Although the results from this detailed study are reported elsewhere, this article contained graphs that showed variation in the fine root biomass (under 2 mm diameter) of the three main species in the stand during the 1974 and 1975 sampling periods. **Vaccinium vitis-idaea** fine root biomass increased steadily each month from 133 g/m^2 in April 1974 to about 175 g/m^2 in September 1974. **Calluna vulgaris** fine root biomass was more constant over the growing season with values of 79 g/m^2, 41, 72, 47, 59 and 63 g/m^2 in the months of April to September, respectively. Fine roots of Scots pine were recorded as 149 g/m^2 in April, 101 g/m^2 in May, 134 g/m^2 in June, 147 g/m^2 and 90 g/m^2 on two sampling occasions in July, 150 g/m^2 in August, and 85 g/m^2 in September.

1. **FRASER, D.A., L. BELANGER, D. McGUIRE and Z. ZDRAZIL**

2. 1964

3. Total growth of the aerial parts of a white spruce tree at Chalk River, Ontario, Canada.

4. Canadian Journal of Botany 42:159-179

5. a. Canada; Index map NL-17; Ontario

   b. White spruce

   c. Biomass (tree)

6. This paper describes a study of apical and radial growth, and needle distribution, of a white spruce tree at Chalk River, a short distance south of the boreal forest region in Ontario. Included in this study are the weights of needles, branches and trunk of an 11 m, 36 yr old white spruce tree. The oven dry weights of needles, branches and trunk for the individual tree are given below.

Needles	14,267 g	17.5%
Branches	28,934 g	35.5%
Trunk	38,329 g	47.0%
Total	81,530 g	

The authors concluded that as more data becomes available it may be possible to interpret the original conditions of growth from knowledge of patterns and structure of the annual rings within the trunk. Although moisture relations are important in influencing tree growth, other factors of the environment such as temperature regimes, including occurrence of late frosts, amount of sunshine, exposure to prevailing winds, nutrient status of the soil, and defoliation by insects, may all be operative either together or at different times in the development of the tree.

1. FREYER, H.D.

2. 1979

3. On the ^{13}C record in tree rings. Part II. Registration of microenvironmental CO_2 and anomalous pollution effect.

4. Tellus 31:308-312

5. a. Northern hemisphere

   b. Scots pine

   c. Climate (carbon dioxide levels), Climate/growth (indirect influences), Climatic change (dendrochronology)

6. Although this study did not deal with trees in the boreal zone, the measurements on Scots pine and several species of hardwoods (Quercus, Aesculus and Fraxinus) near Eifel, Germany (50 40 N, 06 40 E) identified anomalous pollution effects upon registration of ^{13}C in tree rings. The study trees were located in the main exhaust direction at a distance of about 50 to 100 m from a coal-fired foundry. This foundry had been in operation since 1890 and closed down from 1929 to 1949, then restarted in 1950. As a result, the trees had been exposed to a higher than normal CO_2 content from 1950 up to the time of this study; they had also been exposed to other pollutants such as SO_2 and dust particles.

The normal trend of ^{13}C values in tree rings recording increasing atmospheric CO_2 levels can be severely disturbed by other environmental influences. By measurements on selected trees for which the history is known, two non-temperature effects have been demonstrated which reverse the normal trend. There is a pollution effect which seems to diminish the carbon isotope fractionation factor between atmospheric CO_2 and vegetation. The decrease in ^{13}C data during the late 19th and the early 20th centuries in different analyzed trees has been shown to be nearly the same, while the ^{13}C record among individual 20th century trees exhibit larger variations. This may reflect at least partly increasing ambient pollution levels and more acid rain during this century, even when the trees had not been exposed to local pollution sources.

As yet, the SO_2 pollution effect or effects of other pollution sources (other than increasing CO_2 levels) cannot be quantified. The author stresses, however, that these effects need to be considered in the interpretation of ^{13}C tree-ring data in the future.

1. GAGNON, Rejean and Serge PAYETTE

2. 1981

3. Fluctuations holocenes de la limite des forets de meleze, Riviere aux Feuilles, Nouveau-Quebec: une analyse macrofossile en milieu tourbeux. (Holocene fluctuations of the limit of tamarack forests, Riviere au Feuilles, Nouveau-Quebec: macrofossil analysis in organic deposits).

4. Geographie Physique et Quaternaire 35:57-72

5. a. Canada; Index map NO-19; Quebec; B.32

   b. Larch

   c. Climatic change (proxy data), Treeline studies (climate)

6. The aim of this project was to outline the fluctuations of the limit of tamarack forests during the Holocene, based on wood macrofossil evidence collected in organic deposits at Riviere aux Feuilles, Nouveau-Quebec (58 15 N, 72 00 W).

The history of the postglacial treeline is based on an exhaustive collection of more than 700 macrofossils, from which a sampling of 67 macrofossils were radiocarbon-dated. Results indicate that tamarack was present in the area 4500 yr BP. Since then tamarack at least twice transgressed the position of the present treeline: 1) between 3500 and 2700 yr BP, when the maximum treeline expansion towards the north took place; and 2) between 2000 and 1600 yr BP, when a less extensive northward displacement occurred.

Very few macrofossils dated around 2650 to 2400, 2100 to 2000 and 1600 to 1300 yr BP were collected. This is interpreted as a regression of tree populations during these periods. After 1300 yr BP no treeline displacement was registered; however, there were local expansions of tamarack populations between 1000 and 600 yr BP, and regressions between 550 and 250 yr BP. In spite of an intensive search in organic deposits, no tamarack macrofossil was collected further north than 5 km of the modern treeline.

1. CALVANS, U.I.

2. 1976

3. Aboveground biomass of trees harvested in thinnings.

4. IN: XVI International Congress of the International Union of Forest Research Organizations, Oslo, Norway. p. 117-127

5. a. U.S.S.R.

   b. Aspen, birch, alder

   c. Biomass (tree)

6. This paper presents biomass data and equations for **Populus tremula**, **Betula pendula** and **Alnus incana** in the Latvian S.S.R. Weights of leaves, branches and stems were determined by tabulation of regression equations obtained from trees sampled in thinnings.

An example of the information contained in this report is the above-ground biomass of **Alnus incana** which is given as follows.

	Stem diameter (cm)				
	4	6	8	10	12
Component	Above-ground dry weight per tree (kg)				
leaves	0.27	0.60	1.15	2.00	3.14
branches	0.34	0.97	2.21	4.33	7.55
stem	3.80	9.27	17.27	29.27	44.18

With increasing stand age the amount of biomass of branches and leaves of trees with the same diameter decreases. This regularity is more pronounced with aspen, especially with regard to the weight of leaves.

1. GARFINKEL, Harriet L. and Linda B. BRUBAKER

2. 1980

3. Modern climate-tree growth relationships and climatic reconstruction in sub-arctic Alaska.

4. Nature 286:872-874

5. a. Alaska

   b. White spruce

   c. Climate/growth (direct relationships, indirect influences, latitude), Climatic change (dendrochronology), Climatic variation (regional, temperature), Treeline studies (climate, growth)

6. This study, as part of a multidisciplinary investigation of treeline fluctuations in the Brooks Range of Alaska used ring-width sequences of white spruce to define climatic limitations on radial growth at treeline and to reconstruct past climatic variables for Fairbanks, Alaska. Multiple regression techniques were used to analyse climate-growth relationships and the results suggest important modifications to the theory that growth at treeline is limited primarily by summer temperature. Fourteen ring-width chronologies were obtained from sites within continuous forest and treeline environments in the Walker Lake - Alatna River valley of the Brooks Range between 67 00 N and 68 00 N, and from 153 00 W to 155 00 W.

The data from this study indicate that in addition to the expected positive correlation with current summer temperature, growth exhibits a strong positive correlation with previous autumn temperature and negative correlations with previous summer, winter and spring temperatures. The positive response of growth to current summer temperature suggests that warm temperatures can increase rates of net photosynthesis and enhance growth in treeline environments during the growing season. The prominent positive correlation with previous autumn temperature suggests that warm autumn temperatures lead to increased photosynthesis after the end of the growing season, resulting in greater reserves of carbohydrates for the next year. The authors noted that this correlation exists for periods after growth has ceased in the preceding summer, suggesting that photosynthates are put into reserve rather than used for late season growth. In fact, climatic conditions that hasten the cessation of growth during one summer may actually promote increased growth during the next. This hypothesis is consistent with the negative correlation of growth at all sites with previous July temperature, as low temperature near the end of the growing season may cause early termination of growth.

The negative correlation of growth with winter-spring temperature may reflect the adverse effects of winter desiccation. Thawing of foliage precedes thawing of the stem and soil during periods of above-average

Continued ...

Garfinkel, H.L. and L.B. Brubaker. 1980. Continued

temperature. As a result, transpiration is activated while water uptake is inhibited, leading to severe water stress. Coupled with this is an increase in respiration, which, if prolonged, will lead to death of foliage.

While precipitation during certain months is strongly correlated with growth, the responses do not follow clear seasonal trends and are not as easy to interpret as the temperature responses. The positive correlation for summer months of the current growing season suggest that internal water stress can limit photosynthesis at subarctic treeline sites when temperatures are high. Relationships of this type are commonly found on arid or semi-arid sites where moisture stress limits growth. The south flank of the Brooks Range is actually a dry environment, as it receives an average of only 332 mm of precipitation per year.

The reconstruction of average May to July temperatures indicates that the 20th century has been approximately 2.1° C warmer than the 19th century during these months. This reconstructed warming episode is consistent with knowledge of treeline fluctuations in Alaska. In the study area, healthy seedlings are abundant above the present treeline, and upper elevation stands of white spruce are apparently not greatly stressed. These findings indicate a current advance of treeline, already noted in other parts of Alaska and Scandinavia. This expansion of the boreal forest, coupled with the warming trend reconstructed for the past 100 yr, is evidence of the widespread warming that has been observed in other areas of the northern hemisphere during this period. The magnitude of the climatic warming also supports the finding that climatic fluctuations at northern latitudes tend to be more pronounced than simultaneous variations in temperate regions.

1. GIDDINGS, J.L. Jr.

2. 1943

3. Some climatic aspects of tree growth in Alaska.

4. Tree-Ring Bulletin 9:26-32

5. a. Alaska

   b. Spruce

   c. Climate/growth (latitude), Climate change (dendrochronology), Treeline studies (growth, climate)

6. Collection of tree-ring material at timberline in the interior of Alaska and at "latitude timberline" or "tree-line" near the coasts of the Arctic Ocean and the Bering Sea had shown that a widespread climatic stress acts similarly on all spruce trees near the limits of tree growth. The particular stress was tentatively identified with mean June temperature at all weather stations north of the Alaska Range.

Selection of spruce stands for sampling was modified by another aspect of the dating problem, the origin of driftwood. Since driftwood is more likely to be drawn from low, river-bank stands of timber rather than from hillsides or steep slopes, selection of sites for this study was confined to such river-bank sites along the Yukon River.

The author observed that large, shapely trees with widespread lower branches are likely to be young and unresponsive to climatic variations, while trees with dense, close-held upper branches are normally sensitive to climate and free of the age effect that requires standardizing of growth curves. Twisted grain, typical of timberline trees, was less often encountered in the Yukon Flats region than below the confluence of the Tanana River; the phenomenon becomes increasingly common towards the western limit of tree growth in Alaska.

Timberline ring records prove to be closely related to fluctuations from year to year in the mean temperature of the growing season. However, with increasing distance from timberline, river bottom ring variations depart from this relationship until in the Yukon Flats region the record has little in common with recognized temperature changes.

Crossdating is possible between points at treeline and interior timberline as much as 800 km apart, but not between points at treeline and interior river bottoms only a few hundred feet above sea level. The ring record at any point near the extreme limits of tree growth appears to be most closely related to temperature fluctuations of the annual growing season for all north Alaska stations. It is thus believed that timberline parallels, in general, a zone of temperature such as can be represented in two dimensions by the space between two isotherms and

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Giddings, J.L. Jr. 1943. Continued

conceived in three dimensions as a layer that cuts through mountainous regions in the interior and sinks below sea level at the edge of the treeless tundra.

The author suggested that the ring record loses its temperature significance with increasing distance from timberline and becomes a mixed record of temperature of the growing season plus unknown factors. The record may continue to be sensitive and consistent but it appears to be constantly changing as distance from timberline increases.

Timberline appears to be limited by mean temperature of the growing season. Radial growth in timberline trees is largely completed in a four to six week period centred around 1 July. Hence, mean June-July temperatures closely represent the temperature of the growing season. The author's data indicated that curves of timberline tree growth closely approximate the curve of mean June-July temperatures. There is evidence for an even closer relationship to temperature for a month beginning the middle of June and continuing to the middle of July.

Tree growth in the Yukon Flats apparently records something other than direct temperature response. Tree ring chronologies in the Yukon Flats represent some combination of spring snowfall, rainfall and temperature of the growing season. The Yukon Flats record seems to be influenced largely by climatic factors outside the immediate growing season, while the growth fluctuations of timberline trees are related closely to climatic stresses active during the period of greatest cell formation.

The author suggested that although zones of equal temperature are likely to be zones of crossdating it is the degree of relaxation of temperature stress that controls the amount by which tree growth can be affected by some other specific climatic stress.

1. GIDDINGS, J.L., JR.
2. 1947
3. Mackenzie River Delta chronology.
4. Tree-ring Bulletin 13:26-29
5. a. Canada; Index map NR-7/8/9; District of Mackenzie; B.23b
   b. White spruce
   c. Climate/growth (latitude), Climatic change (dendrochronology), Treeline studies (growth, climate)
6. Stands of white spruce (Picea glauca) recorded by the author on the Mackenzie Delta above latitude 67° N, in the summer of 1946, included trees more than 500 years of age. A 16.5 cm radius core of one of these, though an indeterminate number of rings short of center, contained a 589 year sequence of annual rings beginning with the ring for A.D. 1357.

In the oldest specimens, average ring width did not generally decrease with age, but long-period growth suppressions and releases were evident. When such trends were not repeated in the other trees of a group, they were not considered by the author to be of climatic significance.

Tree characteristics differ between areas on the delta and upstream of the delta. Above Fort Good Hope and into the headwaters, including the lower Liard River and the whole of the Fort Nelson River drainage, trees more than 200 years of age are rare in contrast to the old trees recorded by the author on the delta downstream from Fort Good Hope. Why should white spruce reach great age near the extreme limit of tree growth and fail to do so in the more tolerant upriver environment? If one views forest fronts as constantly changing phenomena which take advantage of climatic releases to shift up mountain sides and toward the northern latitude barrier, it is difficult to explain, at the edge itself, the high stability and uniform growth represented by the long-lived trees recorded by the author. Spruce trees growing at their northwestern limit, on the Noatak River, north of the Arctic Circle in Alaska, also showed growth features similar to those of Mackenzie Delta spruce.

Comparison of tree growth on the Mackenzie Delta with weather records from Aklavik showed no strong relation to precipitation but marked agreement to mean July temperature. This contrasts with northwestern Alaska tree-growth, which has been shown to agree best with mean June-July temperature. Maximum growth in the Alaska trees takes place during the latter half of June and early July, while the first cells of 1946 wood were observed in the Mackenzie Delta trees on the second day of July.

1. GIDDINGS, J.L. Jr.

2. 1953

3. Yukon River spruce growth.

4. Tree-Ring Bulletin 20:2-5

5. a. Alaska

   b. Spruce

   c. Climate/growth (latitude), Climatic change (dendrochronology), Treeline studies (growth, climate)

6. The curves and tabulations presented in this report are those of a group of spruce trees growing at about 50-mile intervals along the Yukon River. The Circle group is the easternmost, and the Nulato group is the last westward on the river itself, although a Norton Bay group is added to lengthen the east-west span of the transect. These data supplement the author's 1943 article, "Some climatic aspects of tree growth in Alaska".

The author reconfirmed in this article that spruce growth patterns change along the Yukon River with changes of mean temperature of the growing season.

1. GIDDINGS, J.L. Jr.

2. 1954

3. Tree-ring dating in the American Arctic.

4. Tree-Ring Bulletin 20:23-25

5. a. Alaska

   b. Spruce

   c. Climate/growth (latitude), Climate change (dendrochronology), Treeline studies (growth, climate)

6. The coniferous forests of the world tend to disappear with regularity toward two very different boundaries that are, nevertheless, determined by aspects of climate. These timberlines are the dry one beyond which moisture does not sufficiently nourish the tree and the cold one that does not give the tree enough time to grow. Detailed studies by Scandinavian botanists and foresters have shown that the northernmost forest in their area is limited by the temperature of the growing season. Tree-ring work in Alaska and northern Canada has confirmed this hypothesis.

The rings of spruce trees in northern Alaska and along the lower Mackenzie River have been shown to reflect the temperature of the period of most intensive growth of the trees. This period is somewhat earlier along the sheltered rivers south of the Brooks Range than in the Mackenzie Delta area. Thus, a correlation of spruce growth in northern Alaska is strongest with mean June-July temperatures, while the July mean corresponds most nearly to tree growth in the Mackenzie Delta, as is the case with conifers at the limit of tree growth in Scandinavia. Although northern spruce trees continue to grow during the late summer, their late-forming cells seem to record no appreciable further effect of climate.

Trees that grow in peaty muskeg are often impossible to use because of a variety of ring distortions, including spiralling of ring thicknesses. The author suggested that if the average ring widths of groups of trees spaced dozens of hundreds of miles apart show a strong identity they are reflecting widely manifested departures in summer temperature.

The climatic meaning of certain local belts or blocks of strong cross dating had not yet been solved at the time of this study. The most striking such area was that of the Yukon Flats region in the middle Yukon River, where the sensitive tree-ring record at river bottom differs considerably from the widespread temperature record of trees at timberline on neighbouring mountains.

1. GIDDINGS, J.L., Jr.

2. 1962

3. Development of tree-ring dating as an archeological aid.

4. IN: T.T. Koslowski, Editor, Tree Growth, The Ronal Press Company, New York, p. 119-132.

5. a. Alaska

   b. Spruce

   c. Climatic change (dendrochronology), Treeline studies (climate)

6. Dendrochronological studies in Alaska have been applied with considerable success to correlations with climate, the tracings of sea currents and archaeology. Cross-dating from rings of trees near their northern limits closely parallels fluctuations in temperature of the early part of the growing season. The soil maintains sufficient moisture throughout the year, because of ground frost in most of this region, but coniferous trees of swampy muskeg may be limited by insufficient nutrition where their roots lie in or upon frozen ground during a good part of the growing season. In such circumstances, trees respond to temperature stress. Lines of cross-dating have been shown to follow very closely isotherms of midsummer temperatures and to move from 914 m in the interior of Alaska to sea level at the outer edges of forest to the west and north.

The author's review indicated that since 1936 Scandinavian investigators have assembled evidence of a close relationship between the growth of arctic conifers and temperature of the growing season, yet their chronologies have not been lengthened enough to assist in archaeological dating. Based on observations along the northern treeline from Alaska to Hudson Bay, the author observed that the oldest trees invariably exist at the very forest edge. Trees growing along the banks of the Yukon River are seldom more than 150 or 200 years of age. In contrast, on adjacent mountainsides, trees are 500 years old, the growth of which is uniform but sensitive in ring record. The sensitivity of the trees on upland sites is to mean June-July temperatures. Other researchers have repeatedly pointed out that trees growing in extreme sites are both the most ancient and the most amenable to dating.

1. GORCHAKOVSKY, P.L. and S.G. SHIYATOV

2. 1978

3. The upper forest limit in the mountains of the boreal zone of the USSR.

4. Arctic and Alpine Research 10:349-363

5. a. U.S.S.R.

   b. Larch

   c. Climatic change (dendrochronology, proxy data)

6. The boreal (taiga) zone is the largest vegetation zone of the U.S.S.R., covering approximately 51% of its territory. Many mountain masses with unforested summits and clearly defined upper forest limits are situated within this zone. Observed fluctuations of the upper forest limit appear to be a response to cyclic climatic change. A tendency for increase in this upper limit has been observed in most parts of the U.S.S.R. boreal zone during the last few decades.

In humid regions of the temperate and subarctic zones, the thermal regime of the growing season, especially of the warmest month (July), exerts the primary control on annual radial increment of trees at the upper forest limit. In general, the authors found that tree-ring fluctuations are synchronous in spite of differences in edaphic conditions. This finding leads to the assumption that tree growth is conditioned mainly by fluctuations of thermal regime. The most important depressions in tree growth occurred in the first half of the 17th century and at the end of the 19th century, based on studies of Larix sibirica tree-rings in the polar Urals.

The authors' review of published information on age structure of some tree stands in Scandinavia and in the polar Urals showed that abundant natural regeneration, formation of separate age-structure generations, and increases in the level of upper tree limit correlate with rather long periods (80 to 90 yr, 160 to 180 yr, and 250 to 260 yr) favorable for tree growth, whereas mortality of tree stands and the lowering of the upper forest limit correlate with rather long unfavourable periods. Short cyclic fluctuations of tree growth and of climate (durations of 22 to 35 yr) do not produce significant changes in the position of the upper tree limit.

Various studies have revealed the occurrence of climatic cycles with amplitudes ranging from 5 or 6 yr to 800 or 900 yr. Such cycles have been documented for the Khibiny Mountains, in the Urals, in the northern part of Siberia, and in Kamchatka. Climatic cycles, involving temperature parameters, with amplitudes of 60 to 80 and 140 to 160 yr, appear to have the most significant influence on displacement of the upper forest limit in boreal areas of the U.S.S.R.

1. GRAY, J. and P. THOMPSON

2. 1976

3. Climatic information from $^{18}O/^{16}O$ ratios of cellulose in tree rings.

4. Nature 262:481-482

5. a. Canada; Index map NN-12; Alberta; B.17

   b. White spruce

   c. Climatic change (dendrochronology, proxy data)

6. The authors explored the possibility of using the oxygen isotopic composition of cellulose from tree rings as a 'thermometer' to measure past temperatures. Using meteorological data from Edmonton the authors determined that temperatures can be measured with a precision of approximately ± 0.15° C when averaged over a 5-year period. To investigate variation of ^{18}O-content of cellulose with temperature, the authors studied a white spruce that grew in Edmonton from 1882 to 1969. Detailed climate records for this location have been kept since 1880.

The results show a good correlation between the $^{18}O/^{16}O$ ratio and mean annual temperature calculated on the assumption that growth in any given year stops in September.

The choice of growing period over which the temperatures are averaged is somewhat arbitrary but the September to August and January to December 5-year means differ on average by only 0.1° C. The best correlation occurs with mean annual temperatures for September to August. The correlation with mean summer temperatures is poor.

It has been shown that net photosynthesis and growth in coniferous trees depends markedly on the production of stored foods (sugars from photosynthesis) during the winter, so that winter temperatures may have a direct bearing on the isotopic composition of the cellulose produced the following year.

The empirical results presented by the authors show that the temperature dependence of the isotopic fractionation can be measured and that the climate record in the cellulose is not destroyed by subsequent exchange over a period of up to 90 yr.

1. GRAY, J. and P. THOMPSON

2. 1977

3. Climatic information from $^{18}O/^{16}O$ analysis of cellulose, lignin and whole wood from tree rings.

4. Nature 270:682-683

5. a. Canada; Index map NN-12; Alberta; B.17

   b. White spruce

   c. Climatic change (dendrochronology, proxy data)

6. Measurements of stable isotope ratios on tree rings have proved a promising way of determining past climate. Recent discussions have centred on which component of wood provides the most reliable record. The authors have measured the oxygen isotopic composition of cellulose, whole wood and lignin from tree rings in a white spruce that grew in the Edmonton area from 1882 to 1969.

The $^{18}O/^{16}O$ ratio of cellulose is seen to have a significant correlation (95% confidence level) with mean seasonal temperatures throughout the year of growth. Correlation with mean annual temperature beginning with autumn previous to the calendar year of growth was found to be 0.94. The whole wood $^{18}O/^{16}O$ measurements show significant correlation only with mean temperatures for winter and spring of the calendar year (0.60) yielding a correlation coefficient with mean annual temperature (September to August) of 0.55, significantly lower than that for cellulose.

Also, there seems to be no relation between the amount of lignin present in the wood sample and seasonal temperature and the authors concluded that the lignin component of the wood carries no useful temperature information. The explanation for this may lie in the process of lignification of wood which takes place over a much longer period than that in which cellulose is produced and deposited in the tree ring.

The production of early wood in the tree ring is a rapid process that may use material stored in the tree from photosynthesis late in the previous year and, to a lesser extent, throughout the winter. Late wood production, on the other hand, is likely to use material produced during the growth season of the tree. Thus, isotopic analysis of cellulose from tree rings may well provide an excellent integrator of mean annual temperature including a period before growth actually occurs. In conclusion, for the tree species and climatic zone being discussed, it seems that only cellulose $^{18}O/^{16}O$ ratios have a sufficiently good response with seasonal mean temperature to be used as a reliable indicator of past temperatures. Measurements of $^{18}O/^{16}O$ ratios of whole wood, although much faster to carry out, seem to yield much less reliable temperature information.

1. GRISON, P.

2. 1971

3. Observations on the impact of defoliating insects on primary productivity.

4. IN: P. Duvigneaud, Editor, Productivity of Forest Ecosystems, Proceedings of the Brussels Symposium, UNESCO and the International Biological Programme. UNESCO, Paris. p 369-375

5. a. Northern hemisphere

   b. Nil

   c. Climate/growth (indirect influences)

6. Although there is no specific discussion of boreal forest productivity in this article, the author drew attention to the fact that defoliating insects may have a significant influence on the net primary productivity of forests.

A principle generally accepted by botanists but regarded by most zoologists as paradoxical is that in a relatively balanced forest the influence of animal production on net productivity of the forest ecosystem is negligible. Apart from the fact that invertebrate production is much greater than vertebrate, the author also stressed that a change in the cycle of biogenic elements must be expected when a large part of the foliage is eaten by phytophagous organisms. In this event one gets a litter on the soil surface containing a high proportion of materials of animal origin.

Often phytophage fluctuations proceed by gradations of relatively regular periodicity. As there is phenological coincidence between plant life and phytophagous insects on the one hand and entomophagous species on the other, there is bound ultimately to be a correlation between the rises and falls of phytophagous populations and the biogeochemical cycles on which primary production depends. The author identified this as a subject for future research.

1. GROVEMAN, Brian S. and Helmut E. LANDSBERG

2. 1979

3. Simulated northern hemisphere temperature departures 1579-1880.

4. Geophysical Research Letters 6:767-769

5. a. Northern hemisphere

   b. nil

   c. Climate change (proxy data)

6. A number of long instrumental temperature series and some time series of proxy data were used to reconstruct approximate annual temperature departures from the 1881-1975 average for the interval 1579-1880. The authors' short-cut method used data from only nine stations: a) Vienna, Austria; b) Berlin, Germany; c) DeBilt, Netherlands; d) Finland Tree Rings; e) Innsbruck, Austria; f) Godthaab, Greenland; g) Montreal, Canada; and h) Reykjavik, Iceland.

The climatic reconstruction showed, in particular, the cold period from the 1760's to the 1810's. However, the interval of the so-called Maunder minimum of sunspots, 1645-1715, was not appreciably colder than the surrounding period on a hemispheric scale. There was also a notable temperature increase from 1820 to 1835. Also notable is that for nearly the whole reconstructed 300-year interval there were negative departures of temperature compared with the past century. The amplitude of this departure is only about 1.3° C without notable trend. No significant periodicities were found for any of the solar cycles.

The authors concluded that it was feasible to estimate mean hemispheric temperatures by using a statistical approach. If additional data become available, a re-evaluation of the present reconstruction or even an extension backward of the northern hemispheric temperature may be possible.

1. HAKKILA, Pentti

2. 1979

3. Wood density survey and dry weight tables for pine, spruce and birch stems in Finland.

4. Communicationes Instituti Forestalis Fenniae 96.3. 59 p

5. a. Finland

   b. Birch, Scots pine, Norway spruce

   c. Biomass (tree)

6. This monograph contains biomass data for pine, spruce and birch for all of Finland, based on 1968 to 1972 National Forest Inventory data. The weight tables include only stem material.

The dry weight of a stem is the product of volume and wood density. Wood density refers to basic density which is the dry matter weight per unit volume of green wood. As a great part of the variation of wood density is dependent on the age of the tree, growth rate and genetic factors, it is difficult to explain solely with the help of external tree characteristics. Consequently, it is to be expected that the accuracy of weight tables will be weaker than volume tables, regardless of the amount of data and the care taken in data collection.

Data were grouped into seven climatic zones that extended from north to south in Finland. The zonal distribution is based on the duration of the thermal vegetation season; it is shortest, less than 120 days, in northern zone 1 and longest, more than 175 days, in south-coast zone 7. There were no spruce test trees for zone 1 because most of the zone is north of the area of distribution of spruce.

The author obtained the following estimates of average stem density, by age classes, using data from all of Finland:

	AGE, yr				
	0-25	26-50	51-100	100 +	Average
	Density, kg/m^3				
Pine	378	398	411	413	403
Spruce	371	368	383	401	380
Birch	452	476	589	504	483

The density of pine stems in the northernmost zones is, despite slow growth, lower at a certain age than in central and southern Finland. This is due to the small percentage of summerwood in the northern pine. In spruce, on the other hand, density increases with the deceleration of growth towards the north, for there is no decrease in the percentage of

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summerwood similar to that in the pine. The author's data on wood density by climatic zones within Finland are as follows.

		Climatic zone*					
	Age class	1	2	3	4	5	6
		Wood density, kg/m^3					
Pine	26- 50	381	396	402	398	403	404
	51-100	382	392	410	412	414	412
Spruce	26- 50	-	-	-	370	365	367
	51-100	-	401	403	387	378	381
Birch	26- 50	-	-	-	472	476	477
	51-100	-	-	-	492	485	490

* Most northerly zone is 1, most southerly zone is 6.

The wood density of softwoods is lowest on fertile sites as acceleration of growth has a density-lowering effect. For birch, on the other hand, site has little effect on density because the density of this species is determined primarily by age. The density of pines and spruces growing on peatlands is somewhat higher than it is for the trees growing on mineral soil. This is due, again, to differences in the growth rate.

1. HALL, Charles A.S., Carl A. EKDAHL and Daniel E. WARTENBERG

2. 1975

3. A fifteen-year record of biotic metabolism in the northern hemisphere.

4. Nature 255:136-138

5. a. Northern hemisphere

   b. Mil

   c. Climate (carbon dioxide levels), Climatic variation (temporal)

6. Several scientists have speculated that global productivity and biomass should be increasing because of such factors as plant fertilization from industrially-derived CO_2 enhancement. Others have maintained that global primary production and biomass must be decreasing because of pollution effects, such as from acid rain, or from forest cutting. There are some tree-ring data that support the latter view. If one or the other of these trends is true, there would be a shift in the absolute and relative rates of global photosynthesis, respiration, and their ratio. Earlier attempts to ascertain any such trends from long term changes in CO_2 have been frus..ated by difficulties in distinguishing changes in biosphere retention from changes in the uptake or discharge of other CO_2 reservoirs, principally the sea and industrial sources. The authors of this paper have presented a new model for the examination of such trends which they believe avoids such problems by focusing on potential changes in yearly patterns of atmospheric CO_2.

In the model, the seasonal variation of 6 ppm in atmospheric CO_2 was principally attributed to seasonal changes in net photosynthesis and respiration of the biosphere, although purely physical and chemical criteria such as annual variations in sea surface temperatures may contribute slightly. The long term increase of about 0.8 ppm of CO_2 per year was attributed to atmospheric retention of a fraction of the CO_2 produced by industrial processes.

Using the records of atmospheric CO_2 co..centration for 16 yr at Mauna Loa, Hawaii, the authors did not observe any significant trend in either semiannual net photosynthesis or semiannual net respiration for the period of the analysis. An increase in the photosynthesis/respiration ratio was observed from 1962 through 1968. This increase was not explicable by water temperature changes; the authors assumed that this period was relatively favourable to photosynthesis and/or unfavourable to respiration. There was also some slackening in world food production during 1964 and 1965, although in general annual correlations between the authors estimates of photosynthesis and world food production were not very strong.

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The authors noted several possible sources of error in their analysis. The most important included: an incorrect coefficient for the uptake of CO_2 by the sea; an underestimate of the quantity of CO_2 injected into the atmosphere by man's activities; and possible effects of annual or secular trends in oceanic surface temperature.

The authors tentatively concluded that although industrial processes have altered and often degraded many aspects of the biosphere, there was no evidence for changes in the basic pattern of northern hemisphere biotic metabolism from 1959 to 1972 within the limits of resolution of this model. Either the biosphere was too big to be affected yet or the potentially adverse effects of such things as acid rain, atmospheric dust loading, urbanization or replacement of highly productive forests with less productive agricultural vegetation was approximately balanced by the stimulatory effects of atmospheric CO_2 enrichment and the increased use of fertilizers in agriculture. In addition, the community compensatory effects of forest could tend to dampen potential changes.

1. HAMPICKE, U.

2. 1979

3. Man's impact on the earth's vegetation cover and its effects on carbon cycle and climate.

4. IN: W. Bach, J. Pankrath and W. Kellogg, Editors, Man's impact on climate, Proceedings of an International Conference held in Berlin. Developments in Atmospheric Science, 10, Elsevier Scientific Publishing Company, New York. p 139-159

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels)

6. The author reviewed present knowledge on the role of terrestrial vegetation in the global carbon cycle. The literature is contradictory as to whether the land biota is a net source or a net sink of carbon for the atmosphere. The author urged more detailed study of three possible carbon sinks: a net growth of temperate forests, the delayed decomposition of organic material in the boreal zone, and the transportation of organic and inorganic carbon into the sea by rivers.

The author concluded that the presently unexplained carbon sinks must be on land rather than in the ocean. While the terrestrial sinks discussed to date, such as regrowth of forests, cannot account for all the carbon to be accommodated, other sinks may be responsible. The "detritus" pool has not been thoroughly investigated, especially peat accumulation, incomplete litter decomposition in the boreal zone, removal of terrestrial humus by rivers, and removal of respiratory CO_2 from plant roots, soil animals and microorganisms by groundwater and rivers. It is estimated that these potential, but undocumented, carbon sinks might together account for an annual withdrawal in the order of 1×10^{15} g of carbon.

1. HAMPICKE, U.

2. 1979

3. Net transfer of carbon between the land biota and the atmosphere, induced by man.

4. IN: B. Bolin, E.T. Degens, S. Kempe, P. Ketner, Editors, Scope 13: The Global Carbon Cycle, John Wiley and Sons, Toronto. p. 219-236

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels)

6. In this article an estimate is given of the annual man-induced net transfer of carbon between the atmosphere and the land biota, including soil organic matter. Processes that enhance the atmospheric pool of carbon are: clearing of forests, mostly involving the use of fire, particularly in developing countries of the subtropics and tropics; industrial use of wood; use of firewood; and decomposition of soil organic matter. Transfers in the opposite direction may be affected by world wide 'fertilizing' of ecosystems with CO_2, fertilizing terrestrial ecosystems with plant nutrients other than carbon, and by intentional or inadvertent creation of ecosystems which accumulate high levels of phytomass.

Considerable amounts of phytomass are left as residue and waste after the extraction of timber and industrial wood which causes an additional carbon flow into the atmosphere. This is not only the case in the tropical forest, but also in the boreal forest where the portion of the phytomass wasted may amount to 80% of the total above-ground phytomass. The roles of the northern coniferous forest and the mixed forests in thinly populated areas of North America are difficult to assess.

The living phytomass per unit of area in the taiga is smaller than in temperate and tropical forests, ranging from $13.5 \times 10^3 g/m^2$ at its southern border to only $5 \times 10^3 g/m^2$ of carbon in the northern parts. The author estimated net carbon flow from all clearcutting and wood-producing activities outside the tropics, including the decomposition of waste material as well as the eventual decay of the utilized fraction, at less than one tenth of the amount in the tropics, or at 0.3×10^{15} gC/yr, which may well prove too low.

The net ecosystem productivity of forests and other permanent vegetation is positive as long as phytomass is increasing, whereas it becomes zero in the so called climax state. Whether climax forests can be stimulated to resume net growth once there is more CO_2 available is not known. Since climax forests are always heterogeneous with regard to size and age

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of trees, it is conceivable that they respond temporarily to enhancements of the CO_2 content, until after some decades a new equilibrium is reached and net ecosystem productivity drops back to zero.

Immature forests, as well as the other early and intermediate successional stages, would be able to cause net transfers of carbon from the atmosphere if they responded to a higher atmospheric CO_2 content in an accelerated growth rate. This is all the more the case if these successional systems grow on productive substrates, thereby being exempt from nutrient shortage.

The activities of man-made transfer of carbon to the atmosphere from the land biota have been estimated as follows:

Activity	x10^{15} g C/year
Forest clearing in the Third World	
Industrial use of wood	+3.6
Firewood	+0.3
Soil organic matter decomposition	+0.3
	+0.6
Reforestation	
Regrowth in the tropics	-0.3
Regrowth in temperate regions	-1.0
	-0.5
Growth stimulation by CO_2	-0.3
Growth stimulation by NO_x	-0.2
Sum	+2.5

There is reason to believe that the resulting figure for the net transfer is on the low side since the items indicating transfers from the biota to the atmosphere may be underestimates. The dominant cause for this withdrawal appears to be man's activity in favoring initial and intermediate stages of permanent vegetation, whereas the increase in atmospheric CO_2 or the higher availability of other nutrients, both potentially resulting in an accelerated growth rate, might be of secondary importance as yet. There need not be an increase in net primary productivity due to fertilizing effects whatsoever; there need only be an increase in net ecosystem productivity at the expense of heterotrophic respiration in order to explain a permanent flux of carbon to the land biota.

Regarding the three major forest biomes in the world, it is clear that the tropical forest, though not exclusively the equatorial rain forest, is the most important. Even allowing for extensive regrowth in parts of the clearcut areas, the fluxes to and from the atmosphere cannot be balanced and a net transfer to the atmosphere of at least 2 x

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10^{15} g C/yr, and more probably of 3 x 10^{15} g C/yr is likely, judging from geobotanical observation. In contrast, the temperate forests are an effective sink whose importance may be even greater than estimated before. In spite of intensive logging, the annual gains in phytomass may well outweigh the losses due to harvesting and industrial processing of wood. For the northern coniferous forest the picture is unclear. Since plant growth in the boreal zone is slow, its impacts as a sink is limited in the short run. It cannot be excluded, however, that the boreal zone is a more important source to the atmosphere than assumed up to now.

The idea that the land biota continues to be a sizeable net source of carbon for the atmosphere is inconsistent with the current concepts of oceanic CO_2 uptake and mixing. Though the models developed to date could account for a net transfer from the biota to the atmosphere in the past, in general they require the land biota to be at least neutral, or they even require it to be a net sink of carbon at present, since the ocean is considered to absorb only a relatively small fraction of the annual input of fossil CO_2.

Over thousands of years, man's influence has resulted in a steady decrease in the amount of carbon fixed in wood and in soils. In history, this trend has been countervailed temporarily and locally, examples being the expansion of the forested area during the Thirty Years' War in central Europe (1618-1648), or the more recent recovery of European forests from their generally poor condition until the 19th century which may still be going on at present. Being fully aware of the possible impact of these countervailing effects, the author suggests that it is still hard to believe that the general trend has been reversed completely. However, from direct observation of the world's vegetation it appears that at present the land biota is a net source of carbon of considerable size.

1. **HARE, F. Kenneth**

2. 1950

3. Climate and zonal divisions of the boreal forest formations in eastern Canada.

4. Geographical Review 40:615-635

5. a. Canada; Index maps (all in Newfoundland, Ontario and Quebec); Labrador, Newfoundland, Ontario, Quebec; all boreal forest sections in Newfoundland, Ontario and Quebec

   b. Nil

   c. Climate (precipitation, temperature), Climatic variation (regional, precipitation, temperature)

6. This paper outlines zonal divisions of the boreal forest east of the Manitoba-Ontario boundary, with emphasis on the Labrador-Ungava peninsula. This peninsula has advantages for the study of zonation within the boreal forest because it is a tilted peneplain that rises from low altitudes near arctic treeline at 58° N to about 900 m a short distance north of the St. Lawrence River. The southward rise of altitude has the effect of offsetting to some extent the normal southward rise of temperature. The thermally controlled zonal divisions of the boreal forest are hence widened and can be studied over much greater distances than in Russia or Finland. The same is true on a smaller scale between Hudson Bay and Lake Superior.

In a search for climatic correlations with zonal divisions of the boreal forest, the author tested Thornthwaite's annual potential evapotranspiration. This is a function used to establish the degree of thermal efficiency possessed by a climate. It is an accumulating logarithmic function of monthly mean temperatures, and is thought to express thermal efficiency on the basis of a presumed analogy with the control of growth rates by temperature. The author's forest divisions and estimates of potential annual evapotranspiration along the zonal boundaries are summarized in the table on the following page.

Virtually all studies previous to this 1950 article had suggested that midsummer temperatures control boreal growth rates and that precipitation is largely ineffective as a control. For example, Hustich (1947) reported that the widths of annual rings in Scots pine at Utsjoki, Lapland, were closely correlated with July mean daily temperature; vertical tree growth was likewise related to the July temperature of the previous year. Neither vertical nor radial growth was related to variations in summer precipitation. Similar results were obtained by other Scandinavian workers for Scots pine and other boreal forest conifers. Giddings (1943) stressed the dependence of spruce on summer temperature in both Alaska and the Mackenzie Valley. The widely accepted view that northern

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forests are governed in their growth by temperature, and that precipitation is everywhere adequate to supply the needs of the growth possible under such cool conditions, was also accepted by Thornthwaite in his climatic classification. The author's work confirmed this view. No evidence was found to suggest any control of boreal forest structure by the moisture factor, other than the effects of poor drainage in muskeg area.

Division	Potential annual evapotranspiration along boundaries (cm)	Dominant cover type
Tundra		Tundra
	30.5 - 31.7	
Forest-tundra ecotone		Tundra and lichen-woodland intermingled
	35.6 - 36.8	
Open boreal woodland		Lichen-woodland
	41.9 - 43.2	
Main boreal forest		Closed forest with spruce-fir assoc.
	47.0 - 48.3	
Boreal-mixed forest ecotone		Closed forest with white and red pine, yellow birch, & other non-boreal invaders
	50.8	
Great lakes - St. Lawrence mixed forest		Mixed forest

The open boreal woodland occurs where potential annual evapotranspiration is between 35.6 and 41.9 cm. Its southern limit coincides with Thornthwaite's suggested division between warmer and cooler micro-thermal climates. In other words, the forest-tundra ecotone and open boreal woodland correspond with the cool microthermal province as defined by Thornthwaite. Wide variations in moisture index occur within this division, without any apparent effect on the vegetation. Since moisture is abundant everywhere, it is of interest to speculate on the origins of the widely spaced but fully developed trees and the lichen floor that requires little moisture. The author speculated that the widespread character of this dry type in the open boreal woodland results from physiological drought. Where frost in the soil is still unthawed in July, the season of peak growth, the trees can derive moisture only from the topmost layers of the soil and hence assume a horizontally developed root system. Competition between neighboring trees must then mean that the space between individuals has to be greater.

Continued ...

Hare, F. Kenneth. 1950. Continued

The main boreal forest occupies areas where potential annual evapotranspiration ranges from 41.9 to 50.8 cm. The main boreal forest and the Great Lakes - St. Lawrence mixed forest meet in the middle of Thornthwaite's warm microthermal zone.

At the time of this study, the author had not tested the relationship between thermal efficiency (as measured by potential annual evapotranspiration) and zones of the boreal forest in northwestern Canada. Noting Sanderson's (1948) report on the effects of drought in western Canada, the author speculated that the dependence of growth on thermal efficiency, so strikingly confirmed in the humid boreal zones of the Labrador-Ungava peninsula, may not hold true in the drier west.

1. HARE, F. Kenneth

2. 1952

3. The climate of the island of Newfoundland: a geographical analysis.

4. Geographical Bulletin 2:36-88

5. a. Canada; Index maps NH-21/22, NK/NL-21/22; Newfoundland; all boreal forest sections in Newfoundland

   b. Nil

   c. Climate (precipitation, temperature), Climatic variation (regional, precipitation, temperature)

6. This article confirms for the island of Newfoundland that there is a high correlation between potential annual evapotranspiration (PE) and structure of boreal vegetation, as the author has documented in Quebec and Labrador.

The best forests in Newfoundland occur along the railway in the central part of the island, in a zone where PE is between 45.7 and 50.8 cm.

The "moss-barrens" that are so extensively developed in Newfoundland present many problems. In many cases this treeless vegetation occurs on highlands, where the climate is truly arctic, and in such cases the barrens form a true alpine tundra. But quite often the barrens extend down to very low levels, being well-developed on the south coast and on the Avalon Peninsula at sea-level, in spite of the fact that the thermal efficiency is adequate for closed forest. It is possible that the lack of trees in these areas is due to the excessive wetness of the climate. In general, the moss barrens are most widely distributed in the south, where PE on the low ground is below 48.2 cm. The forest cover is most continuous in the north, with PE above 48.2 cm.

The wetness of the island is emphasized by the degree to which annual precipitation exceeds water consumption by evapotranspiration. Along the whole of the south coast the annual surplus exceeds 76 cm with the result that level areas in this region may be waterlogged to the point that makes forest growth impossible.

1. **HARE, F. Kenneth**

2. 1954

3. The boreal conifer zone.

4. Geographical Studies 1:4-18

5. a. Northern hemisphere

   b. Mil

   c. Climate/growth (latitude), Climatic variation (regional), Treeline studies (climate)

6. This paper reviews the meaning and status of the boreal zone, which refers to the circumpolar forest that spans Alaska, Canada and Eurasia from Atlantic to Pacific. The boreal zone reasonably corresponds climatically to the Köppen subprovinces Dc and Dd, or to a range of potential evapotranspiration from 31 to 52 cm on Thornthwaite's scale of thermal efficiency.

Within this climatic zone numerical dominance is maintained nearly everywhere by the genera Pinus, Picea, Abies and Larix. Broad-leaved species are usually present as sub-dominant or successful elements in the forest, but achieve dominance in only a few areas. The important broadleaved genera are Salix, Populus, Alnus and Betula. The limits and subzones of the boreal forest and the apparent climatic correspondences of these lines and belts were outlined by the author.

The earliest enunciated climatic equivalent for the arctic treeline was the isotherm of 10° C mean daily temperature for the warmest month. Nordenskjöld later amended this equivalent to

$$w + (9.0 - 0.1k)\ ^\circ C$$

where w = mean temperature for the warmest month, and
k = mean temperature of the coldest month.

Neither Köppen's line nor Nordenskjöld's amendment really corresponded with the treeline. The values of 30 to 33 cm annual potential evapotranspiration in Thornthwaite's scale of thermal efficiency gives a better fit, and others have shown that the isopleth with 10° C of accumulated month-degrees above the 6° threshold also fits the treeline very well.

There is no doubt that the arctic treeline is truly a thermal limit. It has been shown that mid-summer temperature (late June, July) is highly correlated in northern conifers with both radial growth and shoot growth. However, the treeline is not in stable equilibrium in all areas and great importance should not be given to the coincidence of present biotic limits with any given climatic parameter.

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At it's southern boundaries, the boreal forest merges with temperate mixed forest or with steppe. The boundary between boreal forest and temperate mixed forest is under thermal control. It has been correlated with the line along which only six months have mean daily temperature above 6° C. This line deviates from the southern boundary by a considerable amount at several points. The best fit seems to come with Thornthwaite's thermal efficiency index, with PE ranges from 51 to 53 cm along humid sections of the southern boundary of the boreal forest.

The forest-steppe boundary visible in western Siberia and in the Canadian prairie provinces is controlled by aridity rather than thermal regime. The author notes that the forest-steppe boundary in both regions is close to the normal thermal limit of the boreal forest. North of this limit, coniferous and mixed forest is able to survive at water deficits as great as those recorded in the grasslands to the south. The author speculates that coniferous forest can maintain itself at water deficits that compel deciduous broad-leaved forest to yield to the grasslands.

Climatic subdivisions, the potential annual evapotranspiration along the boundaries between subdivisions, and dominant cover types are summarized below for the boreal zone:

	Potential annual evapotranspiration along boundaries (cm)	Dominant cover type
Tundra zone		Tundra vegetation
	30 - 33	
Forest-tundra zone		Tundra on interfluves; woodland in valleys.
	33 - 35	
Woodland sub-zone		Lichen-woodlands with less than 50% admixture of closed-crown forest.
	41 - 43	
Closed forest zone		Closed crown forest occupying at least 50% of the mesic sites.
	51 - 53	
Mixed temperate forests zone		Forest dominated by species of non-boreal types, usually deciduous broad-leaved species.

1. HARE, F. Kenneth

2. 1966

3. Recent climatological research in Labrador-Ungava.

4. Cahiers de Geographie de Quebec 19:5-12

5. a. Canada; Index maps NO-19, NO-20, NN-19, NN-20, NN-21; Labrador, Quebec; B.1b, B.12, B.13a, B.32

   b. Nil

   c. Climate (insolation)

6. Modern climatology has shifted interest from the traditional parameters of temperature and precipitation to the budgets of energy and moisture at the earth's surface. It is especially true in arctic and subarctic regions that radiation incomes at soil level may be very high in spring when air temperatures are still near the freezing point. Hence a false impression is obtained if one concentrates wholly on temperature as a means of assessing the growth potential for vegetation. Significantly, the major initiatives in the new climatology have come largely from a northern country, Russia.

A close approximation of energy supply at ground level is given by net radiation (R):

$$R = I(1 - \alpha) + R' - R''$$

where I is insolation (direct and diffuse) and is measured as kilogram-calories per square centimetre (kcal/cm^2, usually called kilolangleys), α is albedo (reflectivity over all the solar spectrum), R' is infra-red radiation received from clouds and atmosphere, and R'' is infra-red radiation emitted from the surface.

Net radiation is the energy available to heat the soil, to create convection in the air above, to bring about evapotranspiration, to melt snow, to permit photosynthesis and ultimately to provide the power for geomorphic processes. Hence its magnitude is of crucial importance. According to Budyko's climatological estimates, the annual value of R is below 20 kcal/cm^2 in northern parts of Labrador-Ungava, and is about 30 kcal/cm^2 along the southern margin. On this peninsula, it is negative (greater than -1 kcal/cm^2 in December) in winter, and positive from March until September. In June it lies near 8 kcal/cm^2, and tends to be geographically very uniform. Direct measurements of net radiation at Schefferville revealed a mean daily net radiation of .258 kcal/cm^2, or a monthly average of 8.7 kcal/cm^2, rather higher than Budyko's computed values.

1. HARE, F.K.

2. 1981

3. Future climate and the Canadian economy.

4. IN: Climate change seminar proceedings, Environment Canada, Atmospheric Environment Service, Downsview Ontario. p. 92-122

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels), Climatic change (hypotheses, proxy data)

6. The existing climate is capable of extraordinary variability, but one can speak of climatic change only if there is a real and lasting shift in the mean precipitation or temperature, or in the probability of extremes. However, the author indicated that scientific opinion is tending to the view that true climatic change is just around the corner, and is in slow progress already. This change is expected to come from the rapid increase of carbon dioxide in the atmosphere, together with a parallel increase in other radiatively active gases such as nitrous oxide and synthetic halocarbons. These effects are the result of human interference - of fossil fuel burning, of forest decrease, of wastage of soil humus, of increased fertilizer use, and of the release of industrial pollutants. They will work towards a substantial warming at the earth's surface, in the view of many authorities. Others have argued that their impact may be lessened by a build-up of particles in the atmosphere from increased volcanic activity, or from smoke or soil deflation. The majority of scientists favour the carbon dioxide effect and hence a warming. In this paper, the author reviewed the possibility of future climatic change, chiefly from the carbon dioxide effect, and the possible consequences for our economy.

The present northern limit of arable agriculture is determined by the rapid decrease northward of frost-free periods, and of summer warmth. The warming predicted from a doubling of CO_2 is about 2.0 to 2.5° C in southern Canada. Such a warming would tend to shift the present agriculturally favourable climates into what is now boreal forest terrain, with infertile podzolic soils. It would tend also to bring the detached Peace River agriculture region into direct contact with the continuously-farmed area.

The present storage of carbon in the biota, chiefly in the woody stems, branches, trunks and roots of shrubs and trees, has been variously estimated from 590 to 828 gigatonnes (1 gigatonne = 10^{12} kg), with annual exchange rates due to photosynthesis and respiration in the range of 50 to 63 gigatonnes/yr. The storage is thus comparable with the 710 gigatonnes in the atmosphere. Forest clearance, with subsequent use of the land for less efficient carbon storage, obviously transfers carbon to

Continued ...

the atmosphere, chiefly due to burning. A recent estimate puts the net transfer to the atmosphere as 0 to 2 gigatonnes/yr, although much higher estimates have also been made.

Large amounts of the world's carbon are stored in the boreal forest formation (about one-eighth of the world total). It has been estimated that total forest storage of carbon in Canada is 44 gigatonnes, and that a further 38 gigatonnes are stored in the huge northern muskeg. These estimates exclude the possibly larger amounts of carbon stored in soils.

The author suggested that one way in which nations can at least slow down the CO_2 buildup is to prevent further wastage of forest biomass. Good forest management should aim at a high level of stored biomass, or standing crop. Much forest exploitation works today in the other direction. In Canada the biomass storage in our forests must have declined substantially since cutting began, in spite of regeneration. In the United States this decline has been halted, and even reversed; the standing crop of marchantable timber has recently been slowly increasing. Canada now faces an era of fully-managed forestry and it should be possible for us to rebuild some of the biomass losses of the past two centuries.

The author shows that, aside from the need to maintain a CO_2 monitoring program, it will be necessary to maintain a watch on climate itself. The natural variability of climate - the noise - is so great that slow changes of temperature and precipitation - the signal - will be very hard to detect. Because Canada covers the range of latitudes likely to be most affected it is important that there be attempts to detect the signal due to CO_2 increase in temperature and precipitation records, and if possible to devise ways of separating this signal from those due to other causes.

The author cautioned that natural systems are apt to be more resilient and homeostatic than we believe. It is conceivable that the climatic system is sufficiently stable to absorb the predicted increases in carbon dioxide and associated effects without striking change. There may be stabilizing processes that we have not yet identified. The author's review indicated that the effects should already be detectable in the high-latitude belt of the northern hemisphere; in fact they are not, so a certain skepticism should be maintained.

1. HARE, F. Kenneth and John E. HAY

2. 1974

3. The climate of Canada and Alaska.

4. IN: Bryson, R.A. and F.K. Hare, Editors, Climates of North America, World Survey of Climatology Volume 11. Elsevier Scientific Publishing Company, New York. p. 49-192

5. a. Canada, Alaska; Index maps (all in boreal zone); All boreal forest regions in Canada

   b. Mil

   c. Climate (air masses, precipitation, temperature)

6. The authors presented a description of the physical climate of northern North America. The central object was to analyze, map and account for the chief physical distributions of the atmospheric or surface-exchange parameters.

Alaska, Yukon, parts of Mackenzie district and British Columbia lie within the western Cordillera of North America. This massive western bulwark is a major control of the hemispheric circulation, blocking low-level penetrations by moist, cloudy airstreams, and imposing long-wave perturbations on the tropospheric flow over the entire continent. Pacific air is not excluded by the mountain barrier, but the air that does penetrate the interior tends to come from well above sea-level, and hence has a rather lower vapor content. The marine influence in the area's climate depends on the surface characteristics of the sea concerned. The Pacific is clearly of paramount importance, because Pacific airstreams are dominant in the continental climate for much of the year. The Gulf of Alaska and the nearby open ocean, from which these airstreams come, are ice-free throughout the year, and there is a considerable flux inland of heat and moisture derived from the ocean surface during the cooler seasons. Actually the North Pacific is not notably warm for its latitude, and the effect is less strong than the equivalent Atlantic effect in northwest Europe.

The Atlantic Ocean plays a smaller role in the climate of the boreal zone than does the Pacific Ocean, partly because Atlantic onshore flow is common only in spring and summer, and partly because there is a broad belt of southward-drifting Arctic water for over 250 km offshore in the Canadian and Labrador currents. Heavy ice pack and some bergs (from Greenland) are carried south in this current as far as northern and eastern Newfoundland. Only between July and November does the ice pack thin out, and the water remains cold and berg-laden throughout this period. Onshore Atlantic airstreams hence reach eastern Canada over a cold surface, and are laden with fog and heavy stratus clouds in summer.

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Hare, F.K. and J.E. Hay. 1974. Continued

The annual rainfall map shows that the southeastern third of Canada - essentially Ontario east of 90 00 W, Quebec and the Atlantic provinces - has much more abundant rainfall than the regions to the west, and the run of the isohyets suggests that this higher precipitation in the east is connected with the flow into the region of moisture from the Gulf of Mexico, the Caribbean and the subtropical Atlantic. The eastern wet region includes eastern Manitoba, all of Ontario, Quebec, the Atlantic provinces (including Labrador) and the high plateaus of southeast Baffin Island; it is the northward continuation of the wet belt of the United States east of about the 95th meridian. Throughout this area, disturbances that create precipitation are vigorous, and the precipitable water from Pacific, Atlantic and Gulf of Mexico sources is sufficient to give a reliable, seasonally well-distributed and usually abundant precipitation. Precipitation variations due to relief are much less pronounced in the east than in the west, even in the mountainous areas, because moving airstreams can carry high vapor contents from a wide range of azimuths.

The northern two-thirds of the eastern wet region has a pronounced warm season maximum of precipitation, with August the wettest month of the annual cycle in most areas. Over Manitoba and northern Ontario, a considerable fraction of total precipitation comes from summer thundershowers, whereas over northern Quebec, south Baffin Island and northern Labrador the bulk falls from frontal rain belts. The remaining third of the region - from the Great Lakes to Newfoundland and southern Labrador - Ungava, including southern Ontario, southern Quebec and the Atlantic provinces - has a seasonally well-distributed precipitation combining heavy and frequent winter snow with equally heavy summer rains, largely of cyclonic origin. In no other area of the world is there so heavy a winter precipitation at so low a mean temperature and low precipitable water.

1. HARE, F. Kenneth and J.C. RITCHIE

2. 1972

3. The boreal bioclimates.

4. Geographical Review 62:333-365

5. a. Alaska; Canada; Index maps (all in boreal region); all boreal forest sections

   b. Nil

   c. Climate (temperature, insolation), Climatic variation (regional, temperature)

6. The authors' central hypothesis is that each zone within the boreal forest has a characteristic structure that represents a specific response to the surface energy and moisture exchanges, and that these exchanges are themselves influenced by the above-surface structure of the vegetation. Each zone, in this view, represents a specific bioclimate in which the physical elements of climate are interlocked with vegetation.

The physical climate of the earth's surface is expressed by two related sets of parameters: those that deal with the storage of heat and moisture in air, vegetation, soil and water; and those that express the rates of exchange of heat and moisture among the various mediums. Logically one ought to add to the list carbon dioxide, stored biomass and other things important to the biota, such as nitrogen and oxygen, airborne nutrients, spores, pollen and contaminants. In this review the authors focus on the surface exchange processes for energy and, secondarily, on those for moisture and implicitly for carbon dioxide.

Global solar radiation in Canada increases southward from annual values near 90 kilolangleys (kly) at the arctic treeline to about 110 kly at the boundary between the open woodland and the closed forest zones except in northern Quebec. More significant is absorbed solar radiation, which ranges from 50 to 55 kly at the arctic treeline to about 80 kly at the northern forest line. For much of the spring the entire boreal forest and tundra are covered by snow and hence tend to have high albedos. In much of the closed forest zone, however, the snow is below the closed-crown coniferous forest, and strong absorption occurs in the leafy area. On the tundra the snow remains intensely reflective; in the open woodland and forest-tundra albedo is between these extremes. The low albedo of dense forest, even when the floor is covered with snow, permits far more rapid warming in spring than over the tundra, and hence a longer season with above-freezing temperatures. With the forest strongly heated and the tundra much less so, an intense air-temperature gradient develops. The thaw pushes northeastward only slowly, taking 25 days to advance 200 km. The duration in days of the thaw season (mean air temperature above 0° C) is about 50 days longer in the closed forest than in the tundra, though these regions are separated by less than 400 km.

Continued ...

The authors conclude that the structure of the boreal vegetation markedly influences the physical climate, just as the climate provides the energy on which plant growth depends. The zonal divisions of the boreal forest in Canada relate closely to the distribution of annual net radiative heating, and even more closely with net radiative heating of the thaw season. Thornthwaite's potential evapotranspiration is less sensitive than net radiative heating as an indicator of zonal division within the boreal forest. Representative values of various thermal parameters for western and eastern portions of arctic treeline and the northern forest line are summarized below.

	Western Canada (100°W - 120°W)		Labrador-Ungava (60°W - 80°W)	
Thermal parameters	Arctic treeline	Northern forest line	Arctic treeline	Northern forest line
Annual net radiation (kly)	18	28	19	31
Thaw season* net radiation (kly)	19	29	22	31
Thornthwaite's P-E (cm)	34	43	28	41
Duration of thaw season (days)*	120	168	145	175

* Period with mean daily temperatures above 0° C. Thaw-season values often exceed those for the entire year because cold-season values are negative.

In Alaska, identification of the zonal divisions is greatly complicated by high mountain barriers near where zonal boundaries might be expected. The mountains interpose broad stretches of icefield and alpine tundra between the interior boreal forest and the Pacific coastal forest. Similarly, the Brooks Range separates the tundra of the arctic coastal plain from the interior forest. The treelessness of the Aleutians, the Alaska Peninsula, much of Kodiak Island, and parts of the southeastern slopes of the Kenai Peninsula cannot be explained on energy grounds. Low summer temperatures, high winds and remarkably cloudy conditions (more than 9/10 in some summer months in many areas) are suggested as reasons for the lack of boreal tree species.

Both biomass and production can be expressed either as mass per unit area (metric tons per hectare) or as the equivalent energy fixed in the dry matter; a gram of dry matter contains 4 to 5 kcal of such stored heat. A figure of 4.8 kcal/g of dry matter is often assumed for the conifer-dominated boreal forest. Of the total energy fixed by photosynthesis, a considerable fraction (more than 40% in some species) is lost by autotrophic respiration. The remainder is the net production, expressed either in t/ha/yr or in kly/yr.

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Energy is important to production, and hence to the biomass standing at a given site, in three ways. First, photosynthesis requires solar radiation in the waveband 0.38 to 0.71 microns, amounting to 40 to 45% of the total solar energy received. This waveband is nearly that of visible light. Second, transpiration in the higher plants requires energy, but this need be of no special wavelength and need not be radiative in origin. Third, the temperature of the plant tissues, of considerable biochemical significance, depends on all forms of energy exchange between the plant and its environment.

Standing plant biomass appears to increase from less than 5 t/ha in the arctic tundra and semidesert to as much as 25 t/ha just north of the arctic treeline. It rises rapidly southward to values as high as 300 to 400 t/ha in the closed forest zone. In relation to the annual net radiation, much more phytomass stands on the land per unit of energy absorbed in the southern boreal forest than in the southern tundra. Growth rises from about 2.5 t/ha/yr near the arctic treeline to near 10 t/ha/yr in the southern closed forest zone. This implies a slow southward increase in the proportion of energy stored as biomass.

The above values for phytomass and annual net production indicate that the potential lifetime of tissues in the tundra and forest-tundra is much less than in the southern closed forest. In the northern and southern subarctic tundra, the annual production is equivalent to a complete replacement time for the phytomass of ten years, whereas in the closed forest, it is equivalent to 25 to 40 years. Presumably this circumstance reflects the increasing role of long-lived woody plants as one goes south.

A close link exists between photosynthesis and transpiration, which depends on net radiation. Hence, there are good arguments for comparing production with net radiation which is the standard Soviet practice. The authors did not attempt accurate estimates of efficiencies of this kind but tabulated approximate percentage energy conversions at the arctic treeline and the northern forest line as summarized in the following table.

Efficiency ratio	Arcti treeline (%)	Northern forest line (%)
$\frac{\text{Net production}}{\text{annual net radiation}}$	0.6 - 1.1	1.0 - 1.2
$\frac{\text{Net production}}{\text{Global solar radiation}}$	0.1 - 0.2	0.2 - 0.4
$\frac{\text{Net production}}{\text{Photosynthetic radiation (mean daily temp. above 10°C)}}$	1.3 - 2.5	1.9 - 2.1

Continued ...

Hare, F.K. and J.C. Ritchie. 1972. Continued

The estimated efficiencies of energy conversion shown in the table above for autotrophs at boreal forest boundaries are annual means. Net production data from Bazilevich and Rodin (1971) were converted to energy on the assumption that 1 g of dry matter contains 4 or 5 kilocalories of fixed heat. The third ratio in the table above is based on the estimate by Tefimova (1971) of available photosynthetically active radiation during the growing season (mean daily temperature above 10° C). The authors used a regression line based on data from Drozdov (1971) which suggested that energy conversions rise from about 0.5% of annual net radiation in the southern tundra, where mean annual net radiation is about 10 kly, to 1.0% in the forest tundra and open woodland, to 1.2 to 1.4% in the closed boreal forest, where mean annual net radiation is above 30 kly.

It is generally assumed that thermal factors rather than moisture conditions control growth in the boreal forest and the authors do not challenge this assumption. They do, however, point out how snow cover is related to vegetation structure in the boreal zone. The physical properties of the snow cover are sensitive functions of the surface aerodynamic roughness, because the surface wind regime and the boundary layer turbulence depend on it. The snowpack of the tundra is quite different from that of the forest-tundra and open woodland zones, and both differ from that of the closed forest. The discontinuous shrub layer of the open woodland zone is a most efficient snow trap, and the shrub species do not survive unless there is a snow cover each winter. Spring albedo and hence radiation income are in turn dependent on the snow cover.

One aspect of boreal bioclimate not dealt with in this article is the relationship between treeline and the arctic front, which separates arctic from Pacific westerly airstreams. This front determines the distribution of atmospheric water vapour and cloud cover in northern Canada and Alaska and hence must have a marked effect on all components of the radiative balance.

1. **HARE, F. Kenneth and Morley K. THOMAS**

2. 1974

3. Climate Canada.

4. Wiley Publishers of Canada Limited, Toronto. 256 p

5. a. Canada; Index maps (all in boreal region); all boreal forest regions

   b. Nil

   c. Biomass (tree, shrub/herb, moss/lichen), Climate (air masses, temperature, insolation), Climate/growth (direct relationships), Climatic variation (regional), Growing season (length)

6. The annotated information below is drawn from Chapter 7 (Climates of the North) and Chapter 8 (Bioclimate and Agriculture) of this review of the Canadian climate, with emphasis on information that reveals relationships between climate and biomass accumulation in the boreal forest region.

Climates of the boreal zone are dominated by arctic airstreams only in winter and spring. In summer and fall they are replaced, on the average, by westerly currents coming mostly from the Pacific. The changeover from arctic to pacific control is fairly early in western Canada, but very late in the east. Hence the arctic and boreal zones lie further south in eastern Canada than they do in western Canada. This effect is accentuated by the deeper snow cover of the east, which retards the warming effect of spring sunshine. The Mackenzie Valley is several weeks ahead of eastern areas of the same latitude in spring break-up and snowmelt. In May, Dawson in the Yukon is as warm as Thunder Bay. Thermal threshold dates for boreal stations are listed in Table 1. Dates shown in the table are estimated to within five days and they represent, for fall, the dates when mean daily values for net radiation (R) fall below zero and the dates when mean daily air temperature (T) falls below 0°C; for spring, the two columns in Table 1 represent the dates when R rises above zero and T rises above 0°C.

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Table 1. Thermal threshold dates for boreal stations

Station	Fall		Spring	
	R under 0	T under 0°C	R over 0	T under 0°C
Whitehorse	Oct 5	Oct 20	Mar 5	Apr 15
Dawson	Oct 1	Oct 5	Mar 25	Apr 20
Inuvik	Sept 25	Sept 25	Apr 5	May 20
Yellowknife	Oct 5	Oct 10	Mar 25	May 5
Beaver Lake, B.C.	Oct 10	Oct 20	Mar 10	Apr 15
Fort McMurray, Alta.	Oct 15	Oct 25	Feb 25	Apr 10
The Pas, Man.	Oct 25	Oct 25	Feb 25	Apr 15
Kapuskasing, Ont.	Nov 15	Nov 1	Jan 30	Apr 15
Sept-Iles, Que.	Nov 1	Nov 5	Feb 25	Apr 25
Goose, Nfld.	Oct 25	Oct 30	Feb 25	Apr 25

R = mean daily net radiation; T = mean daily air temperature

In the arctic and boreal zones, climate depends upon the nature of the land surface, particularly the type of vegetation. For example, a closed crown forest absorbs more radiation than areas above treeline. Close and intimate linkages exist between climate and vegetation in these regions, but the nature of these linkages have yet to be determined in detail. Some known correlation between climatic and biotic distributions are summarized in Table 2.

Table 2. Climatic values typical of northern vegetation zones and boundaries

Zone	Climatic values			
	A	B	C	D
Tundra zone				
Tundra, Queen Elizabeth Islands	5	480	5-10	75
Tundra, southern areas	10	445	10-15	90-120
Arctic treeline	10-13	450	15-20	120-145
Boreal zone				
Forest-tundra and woodland	13-15	400-500*	20-25	150-170
Northern forest line	15	450-500	30	168-175
Boreal forest	15-18	450-525	30-35	180-210
Southern boreal limit	16-18	475-525	35-40	200-225

A: Mean daily temperature, 0°C, July
B: July net radiation, langleys/day, mean value
C: Annual net radiation, kilolangleys/day, mean value
D: Duration of thaw season, days with temperature over 0° C

* Lowest in Labrador-Ungava, highest in northwest.

Continued ...

The authors summarized data gathered on the productivity of different vegetation zones in Canada, Alaska, the Scandinavian countries, and the U.S.S.R. and compared these data to known facts about climate, as summarized in Table 3.

Table 3. Approximate values of phytomass, net annual production, and efficiencies of energy conversion (with respect to dry matter).

Vegetation zone	Phytomass (T/ha)	Net production (T/ha/yr)	Pr_1	Pr_2 Percent	Pr_3
Tundra zone					
High arctic tundra	under 5	under 1	0.5	0.1	1.0
Southern tundra	25	2	0.5-1.0	0.2	1.0-2.0
Boreal zone					
Forest-tundra and woodland	50-150	3-5	1.0	0.3	2.0
Forest	200-400	5-10	1.0-1.5	0.5	2.0

Pr_1 = per cent conversion of net radiation per annum
Pr_2 = per cent conversion of global solar radiation per annum
Pr_3 = per cent conversion of photosynthetically-active radiation received when air temperature is 10°C or over.

The concept of potential photosynthesis was analysed by the authors in terms of Canadian climatic conditions. Photosynthesis depends very little on temperature but greatly upon day length and solar radiation income. Canada is in an area of high potential photosynthesis in summer especially in the Mackenzie Valley and Yukon. The long days and brilliant sunshine favour high yields of plant tissue. The mean value of potential net photosynthesis exceeds 35 g/m^2/day over much of northern Canada and over 37.5 g/m^2/day in the far northwest. These high potential values are applicable only during a short growing season and over a full year net photosynthesis is modest. In agricultural areas, net potential photosynthesis ranges from 15 to 18 g/m^2/day, or 55 to 66 T/ha/year. The actual net production achieved by natural ecosystems (Table 3) is far below these values.

Growing degree days (accumulated temperatures above a certain threshold) are a crude indicator of net radiative energy income during the growing season. This explains the reasonably close relationships between growth of plants and summations of growing degree days.

1. HARMON, R.S.

2. 1980

3. Paleoclimatic information from isotopic studies of speleothems: a review.

4. IN: W.C. Mahaney, Editor, Quaternary Paleoclimate, Geo Abstracts Ltd., University of East Anglia, Norwich, England. p. 299-318

5. a. Northern hemisphere

   b. Nil

   c. Climatic change (proxy data)

6. Natural variations that occur in the isotopic composition of speleothems may, under certain circumstances, provide records of climate changes from the Pleistocene Epoch. Speleothems are inorganically precipitated calcium carbonate deposits (stalctites, stalagmites and flowstones) which are formed within the limestone caves. This proxy information can be of five types: 1) long-term climate trends as delineated from speleothem age distribution in areas of pronounced Pleistocene climate change; 2) paleosea-level fluctuations as determined by dating of speleothems from presently drowned caves in coastal or island karst areas; 3) relative climate change as recorded by $^{18}O/^{16}O$ variations in speleothem calcite; 4) past patterns of meteoric precipitation as reconstructed from D/H variations in speleothem fluid inclusions; and 5) absolute paleotemperatures as calculated from the $^{18}O/^{16}O$ and D/H composition of speleothem calcite/fluid inclusion pairs. Examples of each type were outlined by the author relative to their potential resolution and limitations to Pleistocene paleoclimatology.

Perhaps the most valuable aspect of speleothem paleoclimatology is the prospect of obtaining absolute paleotemperatures. Provided deposition occurred under equilibrium conditions, depositional temperatures can be calculated from a measurement of the $^{18}O/^{16}O$ ratios of fluid inclusion water and host calcite.

1. HARRIS, R.E. and A.C. CARDER

2. 1975

3. Climate of the Mackenzie plain.

4. Agriculture Canada, Ottawa. Publication 1554. 27 p.

5. a. Canada; Index maps NO-12, NP-9/10, NP-11/12, NQ-7/8/9, NQ-9/10/11/12, NR-7/8/9; Alberta, District of Mackenzie; B.18b, B.23a, B.23b, B.27

   b. Nil

   c. Climate (precipitation, temperature), Climate/growth (direct relationships), Climatic variations (regional), Growing season (frosts)

6. The Mackenzie plain extends from Lake Athabasca northwesterly for 1500 km to the mouth of the Mackenzie River. This entire area is within the northern boreal forest and the more northerly part is within a zone of permafrost. Only the area south of Fort Good Hope is considered to have agricultural potential.

Although the factors controlling growth rates of woody species in the boreal zone may differ from those controlling crop growth, the following weather features of the Mackenzie plain are considered by the authors to be favourable for crop growth: summers are warm with a mean July temperature of 65.4° F (18.5° C); over half the yearly precipitation falls during the growing season when the plants need it; long summer days promote rapid development so that crops can mature within the short season; low wind speeds help to minimize evaporation and conserve the limited moisture; and a stable snow cover protects roots and low plants during the cold, dry winter. Weather features considered to be unfavourable for crop growth and livestock include: the short growing season limits the crops that can be grown and prolongs the feeding period for livestock; frequent summer droughts greatly limit crop production; unseasonable late spring and early fall frosts sometimes cause severe damage to crops; wet autumns frequently delay harvest; and long nights and bitter cold in winter cause extreme discomfort to animals and man.

The mean monthly air temperatures over the Mackenzie plain are relatively uniform for such an extensive area, but mean monthly precipitation varies considerably among locations from 1 April to September. Fort Smith has the best rainfall distribution with high precipitation during June and July to promote growth and then low rainfall in August and September which encourages ripening of crops. Yellowknife has the lowest precipitation within the Mackenzie plain, especially during the growing season, and has the least favourable precipitation distribution for crop production.

1. HARRIS, Stuart A.

2. 1981

3. Climatic relationships of permafrost zone in areas of low winter snow-cover.

4. Arctic 34:64-70

5. a. Canada; Index maps (all in Alberta and Northwest Territories); Alberta and Northwest Territories; All boreal forest sections in Alberta and Northwest Territories

   b. nil

   c. Climate (temperature), Climatic variation (regional), Treeline studies (climate)

6. This paper discusses a new method of climatic prediction for specific conditions which are fairly widespread in permafrost regions. It then examines the spatial variation of freeze-thaw indices. If freeze-thaw indices are assumed to be the key to the climatology of the permafrost zones, they can also be used to check the validity of the concept that near-surface temperatures change at a constant rate with climatic change. Such an assumption is needed in predicting world-wide climatic changes using evidence of climatic changes at a single location, and is widely used in palaeoclimatic interpretations.

If the lapse rate is constant, then the plot of freezing and thawing indices along a line of latitude should be a straight line. However, when the 1974-75 indices for the weather stations lying along a line from Medicine Hat via Edmonton, Great Slave Lake to Inuvik were plotted a series of straight lines appeared. Clearly, lapse rates vary abruptly from place to place at certain points on the landscape in a manner not previously considered. In the case of the thawing index, the first break occurs at the boundary between the forest and agricultural zones near Edmonton and again in the lower Mackenzie Valley. The data were corrected for the effects of elevation above sea level but the changes in slope of the lines remained. The freezing index showed breaks near the tundra-forest boundary and the Arctic Ocean, as well as near Lesser Slave Lake and the Hanna-Drumheller area. The latter is the boundary between the agricultural zone and the badlands along the Red Deer River.

A likely cause of the abrupt changes in seasonal lapse rates is the change of albedo from place to place. There are large differences in amount of insolation reaching the ground between bare ground and prairie, while other marked differences occur between these environments and forest.

1. HART, P. and M. LEIKOLA

2. 1974

3. Further development of the dynamic growth model of plant height growth.

4. Flora, Bd. 163: 357-370

5. a. Finland

   b. Birch, Scots pine, Norway spruce

   c. Climate/growth (direct relationships)

6. The authors examined a dynamic model of daily height increment in Pinus sylvestris, Picea abies, Betula verrucosa and Sorbus aucuparia from the Forest Field Station of the University of Helsinki (61 50 N, 24 20 W). In general, height growth of Scots pine increases rapidly in the spring, reaches a maximum of very short duration, and decreases again until the height growth finally ceases in the beginning of July. The height growth of Sorbus increases and decreases even more rapidly than that of Scots pine. The growth intensity of silver birch reaches its maximum level rapidly, is maintained there for several days, after which the intensity of height growth decreases slowly. The latest tree species in Finland to begin height growth is Norway spruce and the maximum height growth of this tree species also lasts only one or two days. The decrease in growth intensity is relatively slow for Norway spruce, and the termination of the growth does not take place until July.

The authors found, somewhat to their surprise, that the growth model did not need any other independent variables than the physiological stage of development of the plant and air temperature. It is conceivable that in boreal, humid climatic conditions the moisture content of the soil is usually high enough to provide trees with the necessary amount of water during the best height growth period so that drought does not have any considerable influence on the height growth of trees. Studies carried out on the influence of various environmental factors on the length of the annual shoot have confirmed the general absence of a moisture-growth relationship in boreal climatic conditions.

On the other hand, it is more surprising that daily solar radiation was not needed as an independent variable in the growth model, since height growth takes place only with energy that comes from photosynthesis. It has been shown that considerable amounts of nutrients move from the youngest needles and leaves directly to elongating shoots. Therefore, if the amount of solar radiation in the open stays above the critical level for photosynthesis (25,000 to 30,000 lux) during most of the days, then height growth of both deciduous and coniferous trees can take place with energy stored in tissues from the previous summer. The strongest correlation between the length of the annual shoot and various environmental variables has been found with the temperature conditions of the summer before the elongation process.

1. HAUGEN, Richard K.

2. 1967

3. Tree ring indices: A circumpolar comparison.

4. Science 158:773-775

5. a. Northern hemisphere

   b. White spruce

   c. Climatic change (dendrochronology, proxy data)

6. In this paper, major fluctuations of tree ring indices representative of the northern treeline are compared and analyzed as indicators of climatic change. Graphical and statistical comparisons of major trends in tree-ring indices representative of interior Alaska, northern Urals, northern Scandinavia and Labrador indicate a highly significant correlation for most 50-yr intervals between 1650 and the present. This is suggestive of similarities in long-term trends of summer temperature on a circumpolar scale. The details of this relationship appear to vary somewhat according to the tree species and the geographical location.

A further relationship involving atmospheric pressure has been suggested. The Scandinavian tree-ring data were suggested to be indicative of probable atmospheric pressure patterns of individual summers, on the basis that summer temperature is closely related to wind and atmospheric pressure conditions. The 25-yr lag between the Scandinavian and Ural indices was tentatively attributed to the same delay observed in frequency trends of the anti-cyclonic situations in western and central Europe, compared with those in eastern Europe. However, investigations at the Alaskan altitudinal timberline did not reveal a statistically significant relationship to any climatic parameter other than temperature.

The inference of similarities of major temperature trends based on tree ring indices can be supported by other evidence. Reported periods of minimal forest growth of Engelmann spruce in British Columbia between 1650 and the present correspond to similar depressions in the index for tree species in the polar Urals, as well as to glacial maxima in northwestern North America. The periods of minimal forest growth in the British Columbia Engelmann spruce correspond generally to the Alaskan as well as the Ural tree indices. The tree index for the interior of Alaska also correlates with glacial maxima in nearby Alaskan mountain ranges.

1. HAUGEN, R.K. and J. BROWN

2. 1978

3. Climatic and dendroclimatic indices in the discontinuous permafrost zone of the central Alaskan uplands.

4. IN: Third International Conference on Permafrost, Proceedings, National Research Council of Canada, Ottawa. Volume 1:392-398

5. a. Alaska

   b. White spruce

   c. Climate/growth (direct relationships, latitude), Climatic change (dendrochronology, proxy data), Climatic variation (regional, temporal, temperature), Treeline studies (climate)

6. Based on correlations of the radial growth of timberline white spruce and June-July temperatures, dendroclimatic patterns of warm and cool growing seasons are documented over the past 300 yr for the Yukon-Tanana Upland of Alaska. Similar timberline tree growth patterns are found south to the Alaska Range and at the white spruce altitudinal timberline in the southern foothills of the Brooks Range. The authors suggest that this indicates a relative uniformity of summer temperature patterns throughout central Alaska.

The authors concluded that the altitudinal timberline position and, by inference, growing season temperatures probably have not changed appreciably in central Alaska for the past 700 yr. Recent warming is indicated by many young trees less than 40 yr old at many interior Alaska locations both above and below the timberline. These observations contrast with studies in northern Canada where seedlings were found only below the timberline, and with others in southern Alaska where fossil wood was found upwards of 76 m above the present altitudinal timberline.

The 10° C July isotherm is the traditional boundary between arctic and subarctic regions in the Köppen and other climatic classifications, and is meant to coincide roughly with the northern limit of tree growth. The 10° C isotherm and altitudinal timberline coincide near the coast in this study, but diverge toward the interior of Alaska. A better fit is obtained by the Nordenskjöld line, defined as $V = 9° C - 0.1 k$, where k = the cold month temperature. This is an empirical formula and there is no physical reason to assume that winter temperatures and the timberline position have a direct relationship. For the upland temperature data of this study there is a close agreement between the Nordenskjöld formula and the position of altitudinal timberline at three sites. In central Alaska, the divergence of the timberline from the 10° C July isotherm appears to reflect the increasing continentality of the climate and is considered by the authors to be a naturally occurring indicator of the annual temperature amplitude.

Continued ...

Haugen, R.K. and J. Brown. 1978. Continued

A dendroclimatic index was developed for the study area. The index displays several distinct intervals of depressed growth, notably the mid-1600's and the early 1800's. The most recent period, since about 1935, suggests the warmest growing season temperatures since the late 1700's. Glacial advances in the northern Alaska Range occurred in 1580, 1650, 1830 and 1875 and agreed closely with the cool intervals indicated by the authors' index. Similarly, other studies utilizing many of the authors' interior Alaska chronologies in a state-wide study of climate noted the cool interval of the early 1800's and the considerably increased warmth in the period 1925 to 1932.

Other studies have noted the distinct warming period from 1925 to 1945. The authors' data confirm the warm period from 1925 to 1945 and also a less pronounced peaking of January temperatures during 1956 to 1965. The period of 1970 to 1975 generally had colder January temperatures, warmer July temperatures, but nearly normal mean annual temperatures. The authors stressed the dominating influence of January temperatures on the patterns of mean annual temperature.

Proceeding across central Alaska there is a gradual shift from maritime climate in the west to more continental climate in the mountainous east. Lowland climates show a decrease in precipitation and an increase in summer temperatures, with no major change in mean annual air temperatures proceeding from west to east. The authors' data and analyses provide estimates of seasonal and annual temperature distribution for upland topography which dominates the eastern half of central Alaska. In western sections the timberline and the 10° C July mean coincide. However in the eastern section these diverge possibly because of the wide range in diurnal temperature fluctuations of the more continental setting. The Nordenskjöld line corrects for the divergence and provides a more realistic estimate of the warm month temperature at the altitudinal timberline as well as an indication of the amplitude of mean annual temperature. These amplitudes in the uplands are smaller than in the lowlands.

The dendroclimatic index for the Tanana-Yukon Upland enables the authors to speculate on the magnitude of growing season temperature changes over the past several centuries. The warming trend since 1930, and the below-normal temperature in the first half of the 19th century, are clearly indicated from the dendroclimatic index. The pre-1800 index shows a predominance of warmer growing seasons. The current age composition of trees at timberline suggests growing season climatic stability for at least the past 300 yr and possibly the past 700 yr, particularly in the vicinity of the Alaska-Yukon border.

1. HEGYI, F.

2. 1972

3. Dry matter distribution in jack pine stands in northern Ontario.

4. Forestry Chronicle 48:193-197

5. a. Canada; Index map NM-16, NL-16; Ontario; B.9, B.10

   b. Jack pine

   c. Biomass (tree)

6. The objectives of this study were twofold: to provide dry matter distribution data for jack pine trees, and to define how age affects dry matter production in jack pine stands. The field work was carried out in natural jack pine stands at two locations in Ontario: in Wells Township, Algoma District and west of Black Sturgeon Lake, Thunder Bay District.

Although the dry matter composition varies considerably between trees, two-thirds of the total dry matter of a tree is, on the average, in the stem. However, the percent of bole dry weight to that of the entire tree increases with age as shown by the following regression:

$$\% \text{ of bole} = 21.95 + 1.76 \text{ Age} - 0.01 \text{ Age}^2 \qquad (R^2 = 0.72)$$

Regression equations of oven-dry weights (o.d.w., kg) of total above-ground tree (T), stem (S), total live crown (total live branches, including needles) (C), lower third of live crown (CL), middle third of live crown (CM), upper third of live crown (CU), needles (N), cones (CO), on dbh (D, cm), using logarithm to base 10 are listed below:

Regression equations	R^2
log (o.d.w. T) = -1.0368 + 2.4206 log D	0.986
log (o.d.w. S) = -1.5481 + 2.7144 log D	0.947
log (o.d.w. C) = -1.1810 + 1.9222 log D	0.773
log (o.d.w. CL) = -1.4178 + 1.7458 log D	0.648
log (o.d.w. CM) = -1.6155 + 1.9969 log D	0.750
log (o.d.w. CU) = -2.2699 + 2.1090 log D	0.829
log (o.d.w. N) = -1.4289 + 1.7188 log D	0.701
log (o.d.w. CO) = -4.9319 + 3.8667 log D	0.716

The above-ground dry matter of standing jack pine in the sample plots was calculated by applying the first regression equation in the table above to the stand table of these plots. The resulting values, shown in the table on the next page, indicate considerable variation primarily because the stands were chosen to represent a range of age and stocking classes on two site types. The total accumulated dry matter in the 16 sample plots, when examined in relation to age, indicate that a substantial

Continued ...

Hegyi, F. 1972. Continued

amount of variation may be explained in terms of stocking intensity Therefore, the stocking ratio of each sample plot was calculated by dividing the basal area of a normal stand by the actual basal area measured on the sample plots. Total above-ground dry matter was then multiplied by the corresponding stocking ratio to give adjusted or normalized total dry matter.

Maximum age (yr)	Total dry matter (kg/ha)	Stocking ratio*	Adjusted dry matter** (kg/ha)
20	16,002	2.807	44,918
20	13,207	4.474	59,088
20	6,865	7.058	48,453
20	7,454	7.675	57,209
30	88,498	0.782	69,205
30	99,213	0.865	85,819
30	61,000	1.224	74,664
30	63,434	1.505	95,468
40	135,733	0.712	96,642
50	126,815	0.856	108,554
65	105,783	1.151	121,756
65	76,046	1.432	108,898
65	53,989	2.182	117,803
65	43,637	2.435	106,256
100	156,826	0.738	115,738
100	126,563	0.935	118,336

* Ratio of normal to actual basal area.
** Total dry matter x stocking ratio.

1. HEINSELMAN, Miron L.

2. 1981

3. Fire and succession in the conifer forests of northern North America.

4. IN: D.C. West, H.H. Shugart and D.B. Botkin, Editors, Forest Succession: concepts and application, Springer-Verlag, New York, p 374-405

5. a. Canada, Alaska; Index maps (all in boreal region); All boreal forest sections in Canada

   b. Black spruce, white spruce

   c. Climate/growth (indirect relationship)

6. Ecosystem theories must encompass the conclusions now emerging from studies of fire and vegetation in fire-dependent northern conifer forests. Such forests comprise more than half the present forest area of North America, including most of the forests that have never been altered through logging or land clearing. Furthermore, vast areas are still influenced by natural lightning-fire regimes, and it is possible to study directly the role of fire in controlling vegetation mosaics and ecosystem function. In this article, the relation of fire to vegetation change in conifer-dominated forests is reviewed for three regions: the boreal forest, the Great Lakes-St. Lawrence-Acadian forests, and the subalpine forests of the Rocky Mountains. Only that part relating to the boreal forest is summarized below.

In the main boreal forest the dominant fire regimes are high-intensity crown fires or severe surface fires of very large size - often more than 10,000 ha, and sometimes more than 400,000 ha. Such fires kill entire stands and, hence, result in total stand replacement. Fire rotations are shorter in the drier regions of western Canada and Alaska, where they average 50 to 100 yr, than in the high precipitation areas of eastern Canada, where they may average 200 yr or more. Fire cycles are also longer near the northern treeline in the subarctic spruce-lichen woodlands than in the closed boreal forests. Cycles of 100 to 150 yr typify the lichen woodlands of the western boreal zone, while in the east cycles may average 150 to 300 yr. The longest cycles in the western boreal zone probably are in floodplain white spruce stands, where they may be 300 yr.

In the north, organic matter decomposition on the forest floor may not keep pace with the accumulation of moss and humus, particularly on cold or wet sites. This potential for net accumulation of biomass has long been recognized in northern peatlands, but its significance on mineral soils and its relation to fire are just now being studied. Unfavourable conditions for bacterial and fungal decay and incomplete nutrient cycling are the causes. Throughout the north, forest fires have been a major

Continued ...

factor in periodically reducing organic layers. Such an accumulation of nutrients in moss and organic layers runs counter to expected trends in temperate forest successions. The author suggests that maximum nutrient cycling may come midway in postfire vegetation sequences and the accumulation of biomass may continue indefinitely in the absence of fire.

On gently sloping mesic to wet terrain, long fire-free periods may allow so much organic matter to accumulate that actual peat is formed, and mineral soil sites become permanent peatland. This process is called paludification. Vast regions have already been paludified in the last 5,000 yr, particularly in the Hudson Bay Lowlands, the glacial Lake Agassiz plain in Minnesota, Ontario and Manitoba, the Ontario Clay Belt, the lowlands of major northern rivers such as the Kuskokwim and Tanana and in several areas in Newfoundland. Periodic fires have apparently burned away increments of peat from time to time, and through their stimulation of nutrient cycling, have retarded peat accumulation. The trend of vegetation change with organic matter accumulation is toward depauperate black spruce raised bogs, or string bogs and ribbed fens, depending on drainage patterns, access to mineral-bearing waters, and other factors. The exclusion of fire accelerates paludification and vegetation changes that can only be seen as "retrogression" in the context of normal successions.

The climate for a year or more preceding fires influences ecological effects because large, high-intensity burns often occur during extended droughts. Fire history records indicate that most of the area burned in a region is generated by a few large fires, which occur at 10 to 20 yr intervals. Extended drought also sets the stage for fires that can consume most of the organic layer.

Season of burn is important. The winter-dry, summer-wet climatic patterns of northern North America influence seasonal effects. The ground is snow-covered from mid-October through May, and fires are only possible when the ground is bare. Snow melt recharges surface soil moisture reserves in April or May, but spring fires still occur because the cured leaves, needles and grasses from the previous summer dry out quickly during short dry periods in spring. Fires are common during spring in the southern boreal and Great Lakes regions, but such fires seldom burn much of the organic layer because it is still cold and wet. Crown fires are also possible at this time. Summer fires come at a time when soil moisture reserves may be much lower, and organic layers may be almost completely dried after significant droughts. Therefore, summer fires are much more likely to consume these layers. In normal years, rains occur frequently through the summer, so it is chiefly in years of unusual drought that major summer fires occur.

Lightning ignitions also vary seasonally. In general, lightning peaks in midsummer, and lightning fires are much less common in early spring or in fall than they are in summer. The annual influx of thunderstorms into

Continued ...

the boreal forests of western Canada occurs as a seasonal wave, entering from the south with the invasion of moisture-laden pacific air into the cold, dry arctic air. This invasion just reaches the subarctic spruce-lichen woodlands in mid-summer, and then quickly recedes southward.

The traditional concept of succession is a consistent, undirectional sequence of changes over time in the species composition of a community, accompanied by parallel structural and functional changes. Most of the vegetation changes in northern fire-dependent forests do not fit this concept. Most species become established in the first few years after fire and apparently many individuals are not eliminated from the site by fire. Their above-ground parts are killed, but they reappear at once through vegetative reproduction. Many arise from seed stored in the canopy or in the organic layer. Many stands regenerate to a composition almost identical to that of the burned stand, but sometimes there are changes because propagules are eliminated by fire, or through an influx of new propagules. Furthermore, many of the visually impressive changes in stands as they mature simply reflect different growth rates of species. Often there is no succession in the tree stratum, either because the first generation trees start out simultaneously, or because there are no replacement species, or fire return too soon.

The author, citing work by Viereck and co-workers, stressed that the phenomenon of moss growth, organic matter accumulation, and nutrient tie-up during long inter-fire periods needs to be understood. Forest floor biomass increases greatly once the tree canopy is established and the feathermosses are abundant. On most of the cooler, more moist sites the forest floor continues to thicken and accumulate material. The criterion for a climax ecosystem that the net increment of biomass should equal zero is not attained.

In summary, the studies reviewed by the author show the following:

1. Most significant fires are large-scale crown fires or high intensity surface fires, causing total stand replacement at cycles of 50 to 200 yr.

2. Fire characteristics and drought strongly influence ecological effects of fire.

3. Many post-fire vegetation changes can be accounted for by prompt species establishment from canopy-stored seeds, organic layer seedbanks, vegetative regeneration, or wind-blown seeds from nearby, and by different rates of growth and senescence of the initial plants.

4. Establishment of feathermoss carpets depends on the development of a conifer canopy.

Continued ...

Heinselman, M.L. 1981. Continued

5. Moss cover contributes to organic layer accumulations, incomplete nutrient cycling, permafrost encroachment, depauperization of communities and bog formation.

6. Fires consume organic layers and recycle nutrients, retarding the trends set in motion by accumulating moss layers.

7. There is no unidirectional development of vegetation, and there are no steady-state communities in boreal coniferous forests.

8. The vegetation is a mosaic of patches of even-aged forest, each patch dating from the last fire but varying in species composition with site factors, propagule sources and fire variables.

9. It is not clear to what extent patch sizes, turnover rates and locations are random as opposed to time dependent.

10. Models are needed to stimulate patch dynamics and system interactions under varying fire regimes.

1. HØEG, O.A.

2. 1956

3. Growth-ring research in Norway.

4. Tree-ring Bulletin 21:2-17

5. a. Norway

   b. Norway spruce, Scots pine

   c. Climate/growth (direct relationships), Climatic variation (regional, temporal)

6. This paper reviews relationships between tree growth rings and climatic factors in Norway. Almost all tree growth ring research in Norway has been based on Norway spruce and Scots pine. In most cases these two species respond in the same way to climatic factors but under some conditions the response has been found to be different. Warm summers usually resulted in broad growth rings in both species. Norway spruce has a greater ability to take advantage of a high temperature in the early part of the growing season, probably because spruce already has new shoots capable of assimilation, while new shoots in pine develop later. Growth in Scots pine is influenced more by a preceding warm summer, because the number of needles increases proportionally more in pine than in spruce. If a warm summer is followed by a year of cold spring and medium summer, the pine may produce a broad growth ring while that in spruce may be narrow.

A year of intensive flowering or seed production may result in a narrow growth ring in both species. In Norway, timber cutting is a far more important cause of improvement in light conditions than windfall or other natural changes, and often has a greater effect on the radial growth than annual fluctuations of temperature and precipitation. Trees suddenly exposed to more light first show a slight decrease in radial growth, followed by a great increase. Maximum growth is reached in the second to fourth year after cutting, and then followed by a very gradual decline.

The author cited work by Slåstad who found interesting results in the upper part of the valley of Gudbrandsdalen. While the growth in the bottom of the valley was influenced by rainfall he found a very high correlation between temperature and growth in pine on the sides of the valley, in altitudes up to 930 m, that is, up towards altitudinal timberline. Summer is short at this elevation, and starts late. This explains why Slåstad found the best correlation between growth and temperature when the temperature factor was calculated from temperature of the last half of June and the whole of July. Growth ring series from trees in the lower portions of the valley were more varied. Maximum growth occurred when very warm and wet summers coincided. Five summers with warm temperatures alone had narrow growth rings. Trees which received meltwater had growth ring relationships to temperature alone.

Continued ...

Hdeg, O.A. 1956. Continued

Along the southeastern coast of Norway the climate is relatively dry, particularly in the early part of summer. The yearly variation in the growth of Scots pine showed a good relationship to rainfall. Three growth characteristics (absolute width of growth rings, number of resin ducts, and latewood percentage) follow three different climatic features, summer rainfall, summer temperature, and July rainfall, respectively. These climatic factors were suggested to be independent to some extent and two of them could be used for checking a crossdating based on the third. Independent analysis of all three growth characteristics may provide a different interpretation of past climatic conditions than examination of growth-ring width alone can do. Evidence for climatic cycles of 3, 5, and 11 yr had been described from some studies.

1. HUGHES, M.K., B. GRAY, J. PILCHER, M. BAILLIE and P. LEGGETT

2. 1978

3. Climatic signals in British Isles tree-ring chronologies.

4. Nature 272:605-606

5. a. Great Britain

   b. Nil

   c. Climate change (dendrochronology, proxy data)

6. The authors present evidence that tree-ring chronologies from sites in the British Isles will provide suitable proxy records for the reconstruction of historical temporal and spatial variation of climate. For a tree-ring chronology to be of value in climatic reconstruction it should have a clear and discernible relationship to climate. The tree-site complex may be considered as a transducer, with external environmental conditions as inputs and a series of changing annual ring-widths as output.

The authors analyzed three British Isles oak chronologies, based on a 14-month "year" for mean monthly temperature and precipitation, commencing in June of the year before growth and ending in July of the year of growth. Physiological evidence suggests that this 14-month period largely contains the periods of latewood formation in both years.

Recorded differences in the response functions for the three chronologies confirmed that the transducer comprising the tree-site complex at each site has a characteristic response to climate. These differences between the response functions may be valuable for climatic reconstruction. By using chronologies that record different elements of climate it will be possible to reconstruct a greater range of climatic variables.

1. HUSTICH, I.

2. 1939

3. Notes on the coniferous forest and tree limit on the east coast of Newfoundland-Labrador including a comparison between the coniferous forest limit on Labrador and in northern Europe.

4. Acta Geographica, Helsinki-Helsingfors, Vol. 7, 77 p.

5. a. Canada, Sweden, U.S.S.R., Index Map NO-20; Labrador; B.32

   b. Birch, White spruce, Scots pine

   c. Climate/growth (direct relationships, latitude), Treeline studies (growth, climate)

6. In general, there is a good correlation between the isotherm of the warmest month above 10° C and the coniferous forest limit. In the case of Labrador, the warmest month is generally August rather than July. The relations between the temperature of an optimum month and the forest limit are about the same in Labrador and in northern Europe. Early studies in northern Scandinavia are cited as evidence that in the continental portions of northern Scandinavia, a somewhat higher temperature of the optimum month is necessary to maintain tree growth than in maritime regions. For continental areas 10.9° C was regarded as the minimum, and 10.4° C in maritime areas.

Studies of relationships between degree-days and tree species distributions in Europe indicated that Betula odorata required a maximum temperature of 14° C for at least 26 days, Picea excelsa required a maximum temperature of 12.5° C for at least 64 days, and Pinus silvestris required a maximum temperature of 17° C for 26 days. The author was unable to provide such data for the Labrador coast study area.

Dense, stunted stands of white spruce are a prominent features of coastal vegetation along the coast of Labrador. Several possible climatic factors were discussed. It was not always possible to distinguish the effects of a strong sea wind from those of low temperature, especially since the sea wind itself lowers the temperature on the Labrador coast during summer. The low summer temperature and the short growth period, combined with fog and comparatively high precipitation, were important points of resemblance between the climate of treeline regions in Europe and that of the Labrador coast. The author suggested that to a certain extent, the forest limit on the southern coast of Labrador was partially determined by the sea wind, while the forest limit farther north on the coast was determined by the sea wind and low summer mean temperature.

1. HUSTICH, I.

2. 1947

3. Climatic fluctuations and vegetation growth in northern Finland during 1890-1939.

4. Nature 160:478-479

5. a. Finland

   b. Scots pine

   c. Climate/growth (direct relationships), Climatic change (dendrochronology), Climatic variation (temporal, temperature), Treeline studies (climate, growth)

6. The author analyzed annual variations in diameter growth of Scots pine at its extreme northern limit in Finland (69 30 N, to 70 00 N).

The growth curves showed a great year to year variation, an obvious low period of growth from 1901 to 1916 and a gradually increasing growth in the 1920's. There was no important seed year for Scots pine during the period of low growth (1901-1916). The same cycles were evident in the production of organic matter in crops such as rye, barley, oats and potatoes in northern Finland.

The author focussed on temperature causes for these growth variations because the influence of precipitation on growth in the far north of Finland was thought to be of only minor significance. July and August temperatures increased appreciably between 1890 and 1939. The positive trend in diameter growth of pine was proportionately higher than the increase in temperature over this period, suggesting that even a fairly small increase in temperature may result in significantly increased growth.

An accompanying note by E.W. Jones provided additional examples to support the northern Finland observation by Hustich. Jones presented growth curves for oak (Quercus sessiliflora) in Hampshire, England and for a silver fir-spruce forest in the Swiss Jura. Both these curves show an increase in mean diameter increment from about 1890 until about 1930, but whereas the Finnish growth curves were unaffected by rainfall, the upward trend of the Swiss and English curves was interrupted by dry periods culminating in 1921 and 1935. The fall in growth from 1930 onwards is shown both in Finland and in England, and it continued throughout the wetter period that followed 1935, so that it may be associated with a fall in temperature - a possibility which is suggested by temperature curves for Switzerland. The Finnish, English and Swiss growth curves all show the general rise in temperature from about 1890 to 1930. The rise in temperature over this period has apparently also been demonstrated in America.

1. HUSTICH, Ilmari

2. 1953

3. The boreal limit of conifers.

4. Arctic 6:149-162

5. a. Northern hemisphere

   b. Balsam fir, black spruce, white spruce

   c. Climate/growth (direct relationships), Climatic variation, (temporal), Treeline studies (growth)

6. At the polar limit there is a marked decrease in the range of soils that can be occupied by the species present. The distinct selectivity is very noticeable at northern treeline where trees grow only on south-facing and well-drained slopes, in the valleys of rivers, in sheltered depressions or on calcareous soil. Conditions favouring the formation of forest tundra and the occurrence of isolated forest stands may vary in different parts of the forest tundra, but microclimatic factors are probably the most important. Cutting of trees by humans may have been important in th removal of tree cover in some areas.

There have been several oscillations of the northern limit of forests in postglacial time, some of which have lasted hundreds of years. Many species near their northern limits are very susceptible to climatic changes, even of short duration. Temperature changes are particularly significant. Isolated stands of trees in the northern part of the forest tundra may possibly be relics from a warmer postglacial period when continuous forest extended further north than it does today.

Between roughly 1900 and 1950 there was a fairly well-marked amelioration of the climate of the forest tundra region of northern Europe. In northern Finland there was a higher incidence of good seed years during the 1920's and 1930's when the radial growth of trees also showed a marked increase. A similar climatic warming occurred in the far north of the U.S.S.R. If any such warming occurred in northern Canada it was less pronounced.

Although the coniferous forest near its northern limit is composed of different species having different ecological requirements, most of them react in a similar manner to the climatic conditions of the region. For example, the effect of wind and snow blast is similar and produces the same pattern of stunted growth in larch, black spruce, white spruce and Scots pine. On average, viable seed is only produced in favourable years near the northern limit of forests. The author noted that, surprisingly, not all tree species near their northern limits have the ability to reproduce vegetatively by adventitious roots, layering, or vegetative shoots; in Scots pine and white spruce vegetative reproduction is rare, whereas it is the rule in black spruce, balsam fir and Siberian fir.

1. HUSTICH, Ilmari

2. 1978

3. The growth of Scots pine in northern Lapland, 1928-77.

4. Annales Botanici Fennici 15:241-252

5. a. Finland

   b. Scots pine

   c. Climate/growth (direct relationships), Climatic variation (temporal), Treeline studies (growth, climate)

6. Near the treeline in Utsjoki, Finland, great annual variation occurs in length of annual shoots on secondary branches of Scots pine. The significant correlation between annual growth variations of pine and temperature during the growing season (particularly July) is illustrated with diagrams, which confirm previous statements and correlation coefficients presented in the author's earlier papers. Serial observations on the annual growth of pine from different places in northern Europe and similar sequences obtained from different habitats are compared. The diagrams show clearly that the annual variation in the visible growth processes of pine are similar over wide areas and that in this connection the quality of the habitat plays only a minor role.

Like growth in length of annual shoots, radial growth also has two stages. The formation of earlywood, the inner part of the tree ring formed in the spring, is partly dependent on the quantity of nutrients stored in the tree over winter. It is for this reason that radial growth is influenced to some degree by temperature of the previous summer. The formation of latewood seems to correlate better with temperature during the current season.

Because length growth does not appear to be much influenced by climatic conditions of the previous growing season, growth in length and radial growth are not necessarily correlated with the same climatic factors. The author's data showed a poor correlation between growth in length and radial growth when they were compared with each other year by year. However, if one pushes the graph of length growth backwards one year, it correlates very closely with the graph of annual radial growth. The author assumed that the growth in dry mass of the whole tree varied less from year to year than would be suggested by the annual variation in annual ring width or in the growth in height of young trees. The author concluded that at the margin of the range of species the growth processes are programmed in detail not only by the inherent structural rhythm but increasingly by both annual climatic variations and long-term climatic fluctuations. Previous researchers had suggested that the trunk of a tree duplicates the history and vicissitudes of growth as written in the branches; this suggested that if branches carry a more complete record of fluctuations in physiological activity than the trunks do, then the study of branches becomes of great ecological importance. It appears that

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Hustich, I. 1978. Continued

branches have less value chronologically but more value ecologically than tree trunks as indicators of climatic influences. The study of variation of the growth in length of annual shoots, and also needle length and flowering intensity, was thought by the author to be significant for an understanding of the ecology of the pine forests in northern Lapland.

The influence of precipitation on growth in length and thickness of pine in the north seems to be less pronounced than the influence of temperature. Owing to the long winter and long period of snow cover, soil moisture in late June and early July is usually high enough to neutralize the effect of occasional dry spells on the growth processes of pine. However, in very dry local habitats, the growth of pine may correlate better with precipitation than with temperature sums.

The author discussed the effect of a few specific years in which the growth processes in question reached an abnormally high peak or deep trough with major effects on tree growth and on regeneration of the species for some time afterwards. Previous authors had described a lag effect where, for example, the effect of a cold summer on the growth processes of one year were still visible as a retarding factor during the following season. However, the effect of one or a series of abnormally extreme conditions may have an overaccentuated effect. For example, in northern Finland during the 1940's and 1950's, pine regeneration and the expansion on pine treeline was noted as an effect of good growing years in the 1920's and 1930's.

The oscillations of northern treeline, both recently and in the past, may have been more dependent on annual climatic variations and key years of climatic extremes, both favourable and unfavourable, than has been previously realized.

1. ILVESSALO, Yrjö and ILVESSALO, Mikko

2. 1925

3. Suomen Metsätyypit Metsiköiden Luontaisen Kehitys- Ja Puuntuottokyvyn Valossa. [The forest types of Finland in the light of natural development and yield capacity of forest stands.]

4. Acta Forestalia Fennica 144:98-101

5. a. Finland

   b. Scots pine, Norway spruce

   c. Climate (temperature), Climate/growth (latitude), Growing season (day-degree totals, length)

6. One of the aims of this study was to determine whether each forest type in Finland was uniform in such a way that the development series of various stand characteristics and their mean values would be similar in different parts of the range from north to south. For this examination Finland was divided into climatic zones according to duration of the growing season and the sum of effective temperature. Isolines of duration of growing season (days) extended across Finland in a generally west-east direction with 180 days at the south tip of Finland and 100 days at the extreme northwest corner of the country. Average sums of effective temperature during the growing season followed isolines very similar to those for length of growing season and ranged from 1350 in southern Finland to 450 in extreme northwestern Finland. Mean temperature of the growing season was highest on the coast of southeast Finland (+13.0° C) and lowest in northwestern Finland (+8.5° C).

A detailed examination was carried out on three forest types that occur in southern Finland, and extend over 350 to 400 linear km and 5 to 6 of the climatic zones. The differences between the average dominant height of trees for the climatic zones and the general age/dominant height curves for the whole range of forest types were rather small. In each of the groups examined, slightly more than one half of the observations differed less than 5%, and slightly more than four-fifths less than 10%, from the average age/dominant height curves for the whole range of the forest types concerned. There were no clear differences between the zones from north to south, apart from a small difference in the northernmost zone. This may have been due to the fact that no distinction was made between the northern subforms of forest types and the main forest types during the early stages of this investigation.

1. JACOBY, Gordon C.

2. 1980

3. Global dendroclimatic data base: arctic.

4. Lamont-Doherty Geological Observatory, Palisades, New York, Contribution No. 3053, unpaged paper prepared for Dendroclimatology Workshop, Norwich, England, 7-11 July, 1980.

5. a. Northern hemisphere

   b. White spruce

   c. Climate/growth (direct relationships, microclimate, latitude), Climatic change (dendrochronology, proxy data), Treeline studies (growth, climate)

6. The forest tundra ecotone and boreal forest of the northern hemisphere have great dendroclimatic potential. These subarctic areas experience greater long term temperature variations than low latitude regions. Information about temperature and moisture conditions are recorded by the long-lived trees of the subarctic where there are few long term meteorological records.

Standard ring width methods, x-ray densitometry, and isotopic methods can aid in reconstructing long term climatic records for the subarctic. With the longevity of some of the widely distributed tree species and the good preservation of dead or subfossil trees, much good material is available for sampling. Most dendroclimatic studies in the north emphasize the temperature signal recorded by tree growth. However, even in trees that are primarily stressed by temperature variations, there often appears to be moisture stress towards the end of the growing season. In their study of the Peace-Athabasca delta area in northern Alberta, Stockton and Fritts (1971) gave evidence that moisture information can be derived by proper selection of tree sample sites in the boreal forest.

The northern treeline ranges from 55 00 N on the south shore of Hudson Bay to 76 00 N on the Taymyr Peninsula. There is a strong asymmetry to the treeline in that nowhere in the western hemisphere does it reach above 70 00 N. This asymmetry and the variations in tree growth patterns along the treeline indicate the lack of homogeneity of the high latitude climatic regions. During individual time periods different sectors of the northern hemisphere may be similar or opposite in climatic trend. In low elevation, low relief areas there is a real latitudinal forest tundra ecotone and treeline. In mountainous areas, local climate is more predominant because slope orientation and local air drainage as well as elevation influence the distribution and growth of trees.

Extensions and outliers of the forest exist beyond the regional treeline. Such outliers are often in local climatic zones such as river valleys in

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Alaska and Canada, or fiords and coastal valleys in Scandinavia. The outliers are often relict stands of trees that now may be unable to regenerate themselves by seed.

Tree cores from the Noatak Valley of northwestern Alaska indicate that during warmer periods cryogenic effects on tree growth can increase. Some sites may experience increased soil movement, tilting of trees and the formation of reaction wood. This abnormal growth interferes with a climatically controlled ring width series. Another effect of permafrost may be interference with soil moisture drainage. This poor drainage can create treeless bogs in areas where climatic conditions are otherwise suitable for tree growth.

The present location of northern treeline approximates the mean summer position of the arctic front and it has been theorized that this frontal position is what controls the limit of tree growth. The detailed configuration of the actual treeline is very complex and defies one simple explanation. All the large scale causes are modified by edaphic and microclimatic factors to produce an irregular treeline. The location of treeline involves air masses and their effect on temperature, precipitation, potential evaporation and radiation. There are areas which appear to be in equilibrium with the climatic factors controlling growth, and areas where tree growth is moving north. It has been suggested that in some areas forests have not yet reached their northern limit due to migrational lag. There may also have been some anthropomorphic modifications of the northern treeline in the Scandinavian countries.

Dating of northern tree rings presents two problems - locally absent rings and ring width variation which may be less than for southern forest sites. In white spruce there are locally absent rings in the periods of extremely low growth which correspond to the Little Ice Age and also a cold period in the mid-1800's. In spruce specimens from the forest tundra ecotone there are often long series of micro-rings on the order of a few hundredths of a millimetre wide. Some of these rings consist of only two cells in the radial direction. Even during less severe climatic periods there can be missing rings. In one site on the lower Coppermine River, there was evidently a catastrophic event affecting two different sites, approximately 8 km apart, where growth was greatly diminished. All the trees sampled at these two locations recorded this event at the same time and individual cores had up to 11 consecutive missing rings associated with this event.

Much northern work has centred on interrelationships between tree growth and temperature. It has been shown that tree ring series can be used to gain insight into past pressure systems. Quantitative reconstruction of temperature parameters have also been made. During the short season of radial growth in the subarctic there are days when the actual air

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temperature may be 25 to 30° C under cloudless skies. A general dendroclimatic assumption in the North is that warmer summer temperatures lead to increased radial growth. With the generally low precipitation of around 250 to 300 mm/yr, a combination of moisture stress and high temperature could reduce photosynthesis on many days during especially warm summers. A negative effect of temperature above optimum combined with moisture stress on photosynthesis could complicate dendroclimatic interpretation of northern tree growth.

In addition to ring width analysis, there may be opportunities for using densitometric methods in dendroclimatology in northern areas. There are considerable variations in latewood density that are readily discernible in microscopic examination and can be quantified by use of x-ray densitometry. Analyses of the stable isotope ratios of hydrogen, oxygen and carbon may provide further information about growth environments. However, these analyses are much more costly and time consuming than tree ring width or densitometric analyses.

The author suggested that in addition to the standard types of meteorological parameters, such as monthly precipitation and temperature, new parameters should also be examined for the purpose of dendroclimatological analyses. Such new parameters should include degree-days above a threshold temperature as a variable affecting tree growth. A parameter similar to the Palmer Drought Severity Index that combines the effect of temperature and moisture could be developed and investigated for northern treeline studies.

1. JACOBY, G.C. and E.R. COOK

2. 1981

3. Past temperature variations inferred from a 400-year tree-ring chronology from Yukon Territory, Canada.

4. Arctic and Alpine Research 13:409-418

5. a. Canada; Index map NQ-7/8/9; Yukon; B.33

   b. White spruce

   c. Climate/growth (direct relationships), Climatic change (dendrochronology), Treeline studies (climate, growth)

6. A time series of ring-width indices from Yukon white spruce trees (65 20 N, 138 20 W) showed growth responses to summer temperature and other climatic variables. The correlations with various temperature parameters were high enough that past temperature information could be inferred for the last 400 yr. The highest simple correlation was between tree growth and total degree-days above 10° C for June and July. A substantial moisture stress in the trees towards the end of the growing season was also indicated. The chronology shows the effects of the Little Ice Age, of the subsequent northern hemisphere warming since the mid 1800's, and of a recent cooling trend since about 1950. According to the tree-ring chronology, summer temperatures in the mid-1800's may have been among the coldest in the last 400 yr.

The meteorological data used were for Dawson, Yukon Territory, approximately 125 km south of the white spruce sample site and separated by a range of intervening mountains. Using an average summer lapse rate developed for the interior of Alaska of -0.6° C per 100 m, the temperature should be about 3.5° C lower at the tree site than at Dawson. The mean annual precipitation could be as much as 25% greater at the tree site than in Dawson.

The relationship between increased radial growth and warmer summers was somewhat empirical, rather than a simple causal effect of warmer air temperature on growth or photosynthesis. In fact higher temperatures can have a negative effect on some growth processes in conifers. Temperatures in this higher range occur on some summer days even at these high latitudes.

The authors noted that above-average moisture in August correlated with tree ring width. Moisture stress late in the photosynthetic season evidently occurs in other forest tundra ecotone areas in Alaska and Quebec where the authors have also conducted studies. It appeared that a colder than average April may result in a positive response in tree growth. This pattern of tree growth response has been noted by the authors at study sites in the Brooks Range of Alaska and at the northern

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Jacoby, G.C. and E.R. Cook. 1981. Continued

treeline in other areas of Canada. Even in a warm April, the root zone is still frozen and transpiration, increased by more thermal energy, could cause desiccation injury. Also, because oxidation of stored carbohydrates is strongly influenced by temperature, a cold April may conserve carbohydrates for the upcoming growing season by maintaining a low rate of respiration.

The fact that tree ring indices seem to carry a signal indicative of year round average temperatures was believed to be due to a degree of parallelism between summer and annual temperature trends.

Trees and meteorological instruments are both imperfect recorders of climatic change - the instruments because each sensing element responds primarily to a single variable, and the trees because they can respond to many variables. The instrumental record is relatively short, especially in subarctic regions, and the usual conversions into grouped or mean values lose information. Tree-ring series contain so much information that there is difficulty in deciphering the record.

1. JACOBY, Gordon C. and Linda D. ULAN

2. 1981

3. Review of dendroclimatology in the forest-tundra ecotone of Alaska and Canada.

4. IN: C.R. Harington, Editor, Climatic change in Canada - 2, National Museum of Natural Sciences Project on Climatic Change in Canada during the past 20,000 years. National Museums of Canada, National Museum of Natural Sciences, Ottawa. Syllogeus No. 33. p. 97-128

5. a. Canada; Index maps NQ-7/8/9, NQ-9/10/11/12; District of Mackenzie, Yukon; B.32, B.33

   b. White spruce

   c. Climatic change (dendrochronology), Treeline studies (climate)

6. The authors reviewed recent activity and past tree-ring studies of northern boreal forests. The review focussed mainly on old-aged trees and long-term dendrochronological studies in the forest-tundra ecotone.

Although temperature effects tend to be regarded as the limiting factors for subarctic tree growth and distribution, the author's results indicate that soil moisture also has substantial influence on northern tree growth. Soil drainage varies from very good in sands and gravels to extremely poor where impermeable till blankets the surface, or permafrost underlies it. In sites on well-drained azonal soils or rocky slopes, one would expect moisture stress to become important to tree growth. In poorly-drained areas excessive moisture inhibits tree growth rates and can create treeless bogs.

In general, variations in tree-ring width are less in the northern boreal forest than in the southwestern United States, where modern dendrochronology developed. Dating is complicated by this relatively low variation. The authors described a tree-ring chronology, dating back to 1550, for white spruce from a site along the Dempster Highway, Yukon. To define the climatic signal in the chronology, response-function analyses were used. These analyses are an efficient method of comparing tree growth with a large number of meteorological factors to identify those which appear most important to growth. The meteorological parameters used were monthly mean temperature, monthly precipitation and degree-days based on records from Dawson, Yukon.

The response-function analysis using monthly temperatures and precipitation indicated that summer temperatures - specifically June and July - were very influential in tree growth at this site. There also appeared to be a dependency on August precipitation. In August, it is still warm enough for some growth processes to occur. Due to low precipitation in this region, apparently above-average precipitation is needed in August for cell enlargement and/or cell-wall thickening.

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Jacoby, G.C. and L.D. Ulan. 1981. Continued

The authors also tested degree-days as a predictor of tree growth. Degree-day parameters have relatively more variance for warm-season months than mean monthly temperatures. Although it is difficult to estimate the most appropriate degree-day base for white spruce, the best response-function results and simple correlations were obtained using monthly values for degree-days above 10° C.

The response-function analyses clearly indicate that there is also a significant moisture signal in the chronology. Moisture stress late in the photosynthetic season evidently occurs in other forest-tundra ecotone areas in Alaska and Quebec. From monthly mean temperature and precipitation response-function results it appears that a colder than average April may play a role in tree growth. This pattern has also been observed in the authors' analyses of tree growth in the Brooks Range of Alaska and at the northern treeline in Quebec. A cold April may conserve carbohydrates for the coming growing season by maintaining a low rate of respiration. Oxidation of stored carbohydrates (respiration) is strongly influenced by temperature. Also, a colder April may prevent the trees from breaking dormancy too early and suffering damage from late-season frosts. The moisture signal, and the inverse relationship between tree growth and April temperature, interfere with the pure June-July temperature signal.

In spite of these complications, the authors noted tree-ring features that they attributed to the Little Ice Age (a period of slower tree growth and narrower rings), a period of several warmer decades beginning around 1770 (a period of faster growth and wider rings), a colder period during the mid 1800's (diminished growth rate), and effects of recent Northern Hemisphere warming (increased growth rate). The chronology indicates that the Dempster Highway study area in the Yukon has recently experienced several decades of climate more favourable for tree growth than the long-term mean taken over the last four centuries.

A large number of samples have also been collected from several sites along the Coppermine River in Northwest Territories, yielding a chronology back to 1428. A response-function analysis, using monthly data from the Coppermine weather station, showed climatic influences similar to the Dempster Highway sites. However, at Coppermine, there is much more dependence on July temperature alone rather than June and July temperature. Moisture stress is relatively low for this chronology based on data from a bench near the Coppermine River. The authors found that Hudson Bay chronologies are all influenced by July temperature, and less by June temperature, than the documented sites in northwestern Canada and Alaska. Weather data from Churchill, Manitoba and Great Whale River, Quebec, all indicate a later, shorter growing season around the southern half of Hudson Bay as compared to higher latitude regions in the boreal zone.

1. JAMES, T.D.W. and D.W. SMITH

2. 1977

3. Short-term effects of surface fire on the biomass and nutrient standing crop of Populus tremuloides in southern Ontario.

4. Canadian Journal of Forest Research 7:666-679

5. a. Canada; Index map NK-17; Ontario

   b. Aspen

   c. Biomass (tree)

6. Biomass and nutrients were estimated for trembling aspen trunk, lateral branch, twig and foliage components in a 30-yr open trembling aspen stand in Wellington County, Ontario. Separate estimates were made for trees in areas subjected to light surface burning and in unburned areas. Allometric relations between a variety of tree measures showed that the best estimates of standing crop were derived from simple log regressions with trunk d.b.h. as the independent variable.

The range of 7.0 to 8.9 t/ha of total aerial aspen biomass was considerably lower than other reported values and reflected both the low stand density and poor site conditions. The aerial biomass estimates indicated that accumulations of aspen standing crop were unchanged by light surface fire. Leaf dimensions appeared to be greater at the crown apex of ramets in burned areas, but this was not reflected by increases in foliage biomass. Marked increases in foliage, including changes in leaf size, of understory and vegetation have been reported, following fires. However, reports of comparable fire-induced changes in the foliage of mature trees are lacking. Little post-burn change was expected in the standing crop of woody components because this was largely accumulated before burning.

The absence of any post-burn biomass changes suggested that the environmental changes resulting from the low-intensity surface fires were not suffficient to produce any appreciable growth modification of mature aspen. Presumably, the massive environmental changes resulting from more severe fires would be reflected by changes in overstory standing crop, if the trees survived.

Distribution of nutrients within the tree components was similar to that reported elsewhere; Ca and N were the two most abundant, while P, K, and Mg accumulations were much lower. Leaves were the site of the accumulation of functionally important N, P, K, and Mg whereas the trunk was the prominent site for structurally important calcium. The total accumulation of all nutrients (103.5 kg/ha) was strikingly low in comparison with amounts reported for other deciduous forests. Accumulation of nutrients in the trunk, lateral branches, and twigs was not appreciably altered by fire.

1. JOHANNESSEN, T. Werner

2. 1978

3. The local climate of the Øvre Heimdalen valley.

4. Holarctic Ecology 1:93-102

5. a. Norway

   b. Mil

   c. Climate/growth (microclimate)

6. The valley described in this article exhibits a microclimate that is transitional between the continentally influenced macroclimate below about 1100 m and the altitudinally influenced subarctic macroclimate above 1100 m. Comparisons were made between the north-northeast valley side with an average 30.0° slope and the south-southwest side with an average 10.5° slope.

The large net input of radiant energy onto the north-northeast side during summer results in higher air temperatures, greater precipitation and higher air humidity than elsewhere in the valley. This is reflected in the luxuriant vegetation on the north-northeast side. No description of vegetation was included in the article. The climate of the study area is strongly influenced by terrain irregularities and reflects how fundamentally different local climates may exist in mountainous regions.

Several climatic parameters discussed by the author were not directly measured but were calculated from assumptions based on similar studies. Radiation balances of the lake surface and the south-southwest valley side are negative from 6 October to 6 April, and from 27 September to 14 April, respectively. Radiation balance of the ground surface on the north-northeast valley side is negative only between 3 November and 6 March. The main reason for this is that effective outgoing radiation is less from a sloping surface than from a horizontal one.

During that part of the year when radiation balance of each individual surface is positive, the net total input of radiation energy amounted to approximately:

80 x 10^4 kcal/m^2 on the ground surface of the north-northeast valley side,
35 x 10^4 kcal/m^2 on the ground surface of the south-southwest valley side, and
55 x 10^4 kcal/m^2 on the lake surface.

The favourable air temperature of the north-northeast side depended on the favourable combination of steep slope angle and excellent exposure with regard to solar radiation during the whole year. The normal air temperature between 1931 and 1960 in the months from June to September

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was calculated to be 8.4° C at 150 m above the lake on the north-northeast side but only 6.0° C on the south-southwest valley side.

A growing period in which the 24 hour mean daily air temperature remains above 6° C lasts 103 days on the north-northeast valley side and 63 days on the south-southwest side. Other growing period indicators such as disappearance of snow cover show a similar relationship between the two valley sides.

The greatest amounts of precipitation fell in summer and early autumn. Summer precipitation mainly occurred as afternoon showers due to vertical convection caused by strong heating of the ground surface. The north-northeast side was heated most and it is therefore likely that the largest amounts of summer precipitation fell on the north-northeast valley side, at least in July and August.

Monthly rates of evapotranspiration on the north-northeast valley side were somewhat higher than those of evaporation from the lake. Monthly amounts of precipitation were also assumed to be larger on the north-northeast valley side than over the lake. Therefore, normal monthly water balance is probably positive from June to September on the north-northeast side.

Wind in the valley was strongly affected by terrain and by local differences in net radiation balance of the ground surfaces. Large local differences in radiation balance of the ground surface within the valley produced an internal circulation of the air. By means of this internal air circulation, sensible heat is transferred from places with positive radiation balance to the air above and from the air to places with negative radiation balance of the ground surface. Such valley circulation on summer days provides a warming of the air during hours with positive radiation balance and a cooling of it during summer nights. Similar conditions also prevailed in winter, particularly in December and January when the radiation balance was negative throughout the day.

The intensity of the transfer of sensible heat increases with the magnitude of the net radiation balance of the ground surface. In summer it was therefore much larger during daylight hours over the north-northeast valley side than the south-southwest side. Winds released by local differences in net radiation balances within the valley were best developed on calm and cloudless days in summer. As the net radiation balance of the ground surface is negative at night, wind directions during the day and night were opposite. Vertical stability of the air in the study area was usually less in summer than in winter. Therefore, in summer, air from higher levels and with great velocity often moved downward into the valley and replaced the surface air on the valley floor. The air came in surges and was observed as strong turbulence with typical gusts and lulls. Gusts of 7 to 8 Beaufort were

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Johannessen, T.W. 1978. Continued

not unusual in the study area on warm summer days. In this way the warm and calm valley air was renewed from time to time.

In winter, and particularly in calm periods with a cloudless sky, the cold and heavy air in the mountains on both sides of the valley moved downslope and settled on the valley bottom where it was further cooled by terrestrial radiation. The concave valley shape enhanced retention of the inversion. Vertical stability of this layer was quite high. With very small wind forces or calm weather the inversion layer may exist for long periods.

1. JOHN, Brian S.

2. 1977

3. The ice age: past and present.

4. Collins, London. 254 p

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels), Climatic change (hypotheses, proxy data)

6. Included in this text is a description of reconstructions of the weather patterns and oceanic circulations during the Little Ice Age. The cold conditions of the Little Ice Age are believed to be related to a global cooling of climate in the North Atlantic that resulted in a southward shift in the depression tracks, carrying summer storms as far south as the Mediterranean Sea. In turn, cold anti-cyclonic storms often affected northern Europe, resulting in snowy, cold winters. Partly as a result of these changes, the Gulf Stream became less powerful, and its warming effect in the northeastern Atlantic declined. The isotherms of sea surface water shifted south, most markedly in the Norwegian Sea and North Sea. The east Greenland current began to export much more arctic pack ice than previously, and pack ice began to affect areas well to the east and south of Iceland. Evidence interpreted from Greenland ice core samples has supported this theory. The main conclusion is that this episode was one during which there was a reduction in the amount of solar energy reaching the earth's surface, leading in turn to a weakening of the atmospheric circulation and hence to a chain of reactions.

Research describing possible changes in global climate due to the activities of man is also described. Since industrialization, vast quantities of fossil fuel have been burned, with two major atmospheric consequences. The carbon dioxide content has gone up, and the amount of atmospheric dust has increased. Between 1880 and 1940 the carbon dioxide in the atmosphere increased by 11%. The overall warming was sufficient to raise global temperatures by 0.3° C between 1880 and 1950.

However, since about 1950 overall world temperatures appear to have decreased due to the increased dustiness of the atmosphere. Dust includes natural sources such as volcanic eruptions and large scale sandstorms, as well as industrial pollution. The scale of dust pollution has increased during the past century. In the U.S.S.R. measurements have shown that atmospheric dust reduced the local receipt of sunshine by 10% between 1940 and 1967. The dust also reduces the temperature of the earth's surface by itself absorbing heat from the sun's rays. Some incoming radiation is reflected back into space by dust particles, and this may be the main mechanism by which dust causes global climatic cooling.

1. JOHN, Brian S., Editor

2. 1979

3. The winters of the world: earth under the ice ages.

4. David & Charles, Newton Abbot, England. 256 p.

5. a. Northern hemisphere

   b. Nil

   c. Climatic change (hypotheses)

6. Included in this book is a discussion of climatic variations of different time scales. Climatic or weather shifts have been plotted on time scales ranging from weeks to seasons, years, decades and centuries. The first order of fluctuations have periods of 25 to 100 yr and result in relatively minor changes, such as short-lived glacier surges. Changes in short-term solar radiation may be important, and the short-lived climatic oscillations seem to correlate with the sunspot cycles of 11, 22 and 44 yr.

Some of the patterns of change that have been recognized can be explained as random, while others may be related to gradual changes in atmospheric circulation. On a scale of years or decades, feedback mechanisms may operate, with such factors as northern hemisphere snow cover, routes taken by atmospheric depressions, and ocean temperatures affecting one another in complex ways. There appear to be links between global weather patterns and changes in the magnetic field, particularly on a scale of centuries and millenia.

It has also been suggested that there may be links between sunspot activity, earthquakes, volcanic eruptions and changes in climate. Palaeotemperature changes recorded in ice cores from Greenland indicate, in addition to an apparent 13,000 yr cycle associated with major ice expansions and contractions, oscillations with intervals of 180 yr, 80 yr and 30 to 40 yr. The causes of these oscillations are imperfectly understood.

The most important of the medium scale oscillations of climate appears to bring a world-wide lowering of temperature every 2,500 yr or so. There have been several widespread and violent oscillations of ice margins since the end of the last glaciation of Scandinavia and North America. The latest of these cool periods was the Little Ice Age. There is evidence that this periodicity of 2,500 yr is related to pulsations in solar radiation.

1. JOHNSON, E.A. and J.S. ROWE

2. 1977

3. Fire and vegetation change in the western subarctic.

4. Department of Indian and Northern Affairs, Arctic Land Use Research Program, Ottawa. ALUR 75-76-61. 58 p

5. a. Canada; Index map NP-12/13; District of Mackenzie B.27, B.32

   b. Nil

   c. Climate/growth (indirect influences), Treeline studies (climate)

6. This study assessed fire frequencies for a portion of Canada's subarctic forest that is used in winter by barren-ground caribou. Fire frequency was related to environmental parameters and vegetation change. A second objective was to study changes in the composition of vegetation on uplands following fire and to describe quantitatively these changes in plant populations along temporal and environmental gradients. The study area was within the western subarctic forest of northern Canada, extending from 60° N to the treeline and from 104° W to 112° W.

The climate of the boreal-tundra ecotone in central Canada has a narrow transition zone between the cool, dry stable arctic air mass to the northeast and the warm, moist unstable Pacific air mass to the southwest. This zone of climatic transition moves seasonally across the region in a northeast-southwest pulse occupying a modal July position in the region of treeline. After July the zone retreats southwest, reaching a modal winter position near the southern boundary of the boreal forest. This transition zone is usually associated with increased frontal activity.

Over a ten-year period, 398 forest fires occurred within the study area. Lightning caused 87% of the fires. The total area burned was 688,000 ha, with large variations in the amount burned from year to year. These results are similar to other areas of boreal forest in Alaska, Yukon and Mackenzie Valley. Fire incidence seemed to follow a seasonal pattern advancing from the south toward treeline in summer and retreating in fall. This leads to the recurrence of more and larger fires in the southwest and fewer and smaller fires in the northeast.

The seasonal patterns of lightning fires appeared to be related to the conditions associated with air masses and their movements. Lightning storms usually occur in areas under the influence of maritime Pacific air, either along fronts or within isolated convective systems. Years in which few fires occur have been shown to be related to above normal precipitation during the summer fire season.

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Johnson, E.A. and J.S. Rowe. 1977. Continued

Meteorologically, above normal precipitation seems to result from an anomalous surface water temperature in the north Pacific. This anomaly gives rise to an amplified long Rossby wave which increases the convergence along the contact between maritime Pacific and continental arctic air masses.

The authors developed a quantitative method of fire frequency analysis. There were two parameters of interest in the formula: 1) the scale parameter "b" characterizes the expected recurrence of fire with a small value indicating a short time in years between fires; 2) the shape parameter "c" determines the shape of the distribution of intervals between fires. A shape value of approximately 3.6 gives the normal distribution, and values less than this give a more positively skewed distribution. In four study areas, the difference between the expected and observed distributions were less than those expected by chance. The fire frequency parameter estimates for four study areas were as follows:

		b (years)	c (shape parameter)
Whirlwind Lake	(60 13 N, 108 42 W)	55.51	2.64
Pilot Lake	(60 31 N, 110 43 W)	69.02	3.19
Rutledge Lake	(61 44 N, 110 30 W)	96.75	2.13
Siltaza Lake	(62 12 N, 109 38 W)	101.11	4.43

The authors presented an argument that related expected fire recurrence time parameter (b) to regional climate and the shape parameter (c) to local topography and substrate. The expected fire recurrence should change in a consistent manner between regions as the air mass climate and ignition pattern change. In the area east of Great Slave Lake, the air mass climate generally changes perpendicular to treeline. From other data sources, it was shown that likelihood of fire occurrence decreases towards treeline, and incidence of lightning also changes perpendicular to treeline. The expected fire recurrence parameter (b) should increase toward treeline. That is, as the regional climate becomes less conducive to fire, the expected time between burns should increase. The data of this study confirmed that the interval between fires increased as treeline was approached.

In regions of smooth terrain, the differences in fire susceptibility between sites were greatly reduced, and the age differences between sites take on a random distribution around the expected value. In varied terrain, the difference in fire susceptibility between sites is larger and thus a greater variety of ages between fires is found. In rougher terrain, there are more older fire-resistant sites and the distribution is positively skewed.

1. JOHNSTONE, W.D. and E.B. PETERSON

2. 1980

3. Above-ground component weights in Alberta **Populus** stands.

4. Environment Canada, Canadian Forestry Service, Edmonton. Information Report NOR-X-226. 18 p

5. a. Canada; Index maps NN-11, NN-12, NM-11; Alberta; B.17, B.18a, B.19a

   b. Aspen, balsam poplar

   c. Biomass (tree)

6. This report presents equations for estimating the above-ground component weights and leaf area index of aspen and balsam poplar in Alberta. Data were obtained from 254 aspen and 60 poplar trees from six study sites, four of which were in the boreal region of central Alberta, one at the southwestern fringe of the aspen-grassland transition (B.17) and one in the montane forest region of southwestern Alberta.

The equations were based upon stem diameter at breast height and total height and provide additive component weight estimates. Although reasonable average estimates may be expected over a number of stands, large discrepancies may occur for individual stands or plots when an equation x stand-table approach is used. These discrepancies may be due to genetic variation between the different clones sampled. Stand density and total standing crop show a strong inverse relationship. The relationship for the fully stocked stands of Alberta's boreal and montane forest regions differs significantly from that for the grove-type stands of the aspen-grassland transition zone of southwestern Alberta.

The measured total standing crop of **Populus** stands varied from 8.7 t/ha in a dense (128,330 stems/ha) 5-yr-old stand to 325.1 t/ha in a 72-yr-old stand containing 1,500 stems/ha. The latter is substantially higher than any previously reported total standing crop for aspen. An inverse relationship was noted between the total standing crop and number of stems per hectare for fully stocked boreal and montane stands with no distinct canopy openings, and this relationship was statistically different from the one for the isolated groves of the aspen-grassland transition. The number of stems is related inversely to age. The relationships between the number of stems per hectare and the bole, crown, and total above-ground standing crops of closed **Populus** stands of the boreal and montane forest regions are shown in the table below.

	r^2
L_n bole dry weight (t/ha) = 14.479 - 1.1605 L_n no. stem/ha	0.892
L_n crown dry weight (t/ha) = 5.414 - 0.3352 L_n no. stem/ha	0.513
L_n total dry weight (t/ha) = 11.438 - 0.7865 L_n no. stem/ha	0.946

Continued ...

Johnstone, W.D. and E.B. Peterson. 1980. Continued

Standing crop density, the apparent density of organic matter per unit volume of forest stand space, varied from 0.54 to 1.63 kg/m^3. This range is somewhat broader than the 1.0 to 1.5 kg/m^3 suggested for fully closed stands by Kira and Shidei (1967). Unlike Kira and Shidei, who reported that dry matter density is practically independent of stand height, the authors found that standing crop density increased with stand height. The relationship between standing crop density and number of stems per unit area is hyperbolic.

The observed leaf area indices of the **Populus** stands varied from 2.41 to 5.39 m^2 leaf surface/m^2 land surface. The results tend to suggest a slightly higher leaf area index for balsam poplar than aspen stands. Leaf area index was not significantly correlated with the number of stems per hectare. This lack of correlation between mean stand height and leaf area index may occur because live crown length seems constant once aspen trees reach 15 to 20 yr of age. As a result, a young aspen stand has a large leaf system relative to the amount of respiring tissue present in the stem, branches, and leaves, so that the net difference between photosynthesis and respiration is high and results in rapid growth. In older stands, the photosynthetic component (leaf area index) is not proportionately larger relative to the much larger biomass of respiring tissues, so that the gap between photosynthesis and respiration is smaller, and growth drops off.

1. **JONES, Gareth**

2. 1979

3. Vegetation productivity.

4. IN: D. Davidson and J. Dawson, Editors, Topics in Applied Geography Longman, New York. 100 p

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb, moss/lichen)

6. Included in this discussion of world patterns of natural vegetation production are references to the boreal regions of the northern hemisphere. The extent of the boreal forests is not substantially different from that in the recent past for planting of cut forests is now almost universal policy.

An important reason for the success of conifers in the boreal zone is their very efficient photosynthesizing ability. This is reflected in the very high leaf area index values recorded for conifers. Walter (1973) has shown that the leaf area index increases as harsher environmental conditions are encountered; thus at the southern margin of coniferous forest a leaf area index of 9 is recorded in the pine forests while at the northern boundary only the most hardy spruces survive and they may achieve a leaf area index of 11. Lieth (1973) quotes an exceptional leaf area index value of 16 for some coniferous species. In all probability the high leaf area index values shown by conifers compensate to some extent for the adverse variables that work against the growth of trees in boreal regions. Nevertheless, this compensation effect does not allow the conifer to be a massive producer of protoplasm.

The author cited data from Lieth (1973) which indicated that in the boreal zone net primary production is in the range of 200 to 1,500 g/m^2/yr with a mean of 500 g/m^2/yr. Whittaker and Likens (1973) have suggested a slightly higher mean of 800 g/m^2/yr while Bazilevich et al. (1971), give figures for eight different taiga types, based mainly on soil differences, in which net primary production ranges from 400 g/m^2/yr for northern taiga on gley-permafrost soils to 1,000 g/m^2/yr for southern taiga on yellow-podzolic soils.

Biomass values are more complicated to calculate and compare than are production values, for within the coniferous forest a large proportion of the biomass is locked up within needle litter. Although conifers are labelled 'evergreen' they do in fact renew between 25 and 33% of their needle complement each year. Bazilevich et al. (1971) gave a boreal biomass range from a low value of 80 t/ha for taiga on boggy sites to a maximum to 350 t/ha for southern taiga on yellow-podzol soils. North American data suggest a slightly higher biomass value, with Lieth (1973)

Continued ...

Jones, G. 1979. Continued

giving a biomass range of 200 to 520 t/ha and Whittaker and Likens (1973) 200 t/ha. In general, in comparison with most other natural woodlands the northern coniferous forest is a low producer.

The following is a summary of values for net primary production, biomass and leaf area index for the boreal zone from references cited by the author:

Net primary production ($g/m^2/yr$) Range	Mean	Biomass (t/ha)	Leaf area index (m^2/m^2)
200 - 1,500 (1)	500 (1)	290 (2)	6.7 (3)
400 - 1,000 (4)	800 (5)	80 - 350 (4)	14.8 (5)
350 - 560 (6)	?	200 - 520 (1)	9.0 (1)
400 - 2,000 (5)	?	398 (5)	11.0 (1)

1. Lieth (1973); 2. Walter (1973); 3. Satoo (1965)
4. Bazilevich et al. (1971); 5. Whittaker and Likens (1973)
6. Newbould (1970)

The boreal forest has a relative lack of other distinct strata of smaller trees, shrubs and herbs beneath the tree canopy, unlike the marked layers of vegetation that characterize more southerly forests. The major reason is the lack of solar energy; by the time solar radiation has passed obliquely through the atmosphere and distributed itself over the surface of the earth there is relatively little energy available for photosynthesis. The evergreen habit of the conifers is one way of optimizing available energy input. Even in 'open' coniferous forest where trees are widely spaced, the trees cast a heavy shade upon the ground and consequently there is insufficient energy available for a luxuriant ground flora. Other factors which mitigate the formation of vegetation layers are the impoverished soils with low nutrient availability. Walter (1973) gave figures to show that the soils beneath a spruce forest are 2° C cooler than soil temperatures of open ground. This is due to the inability of radiation to reach the forest floor. The temperature gradient is the opposite from that found under deciduous mid-latitude forest where the forest soil is invariably several Celsius degrees warmer than soil temperatures of adjacent non-forested areas. In mid-latitude sites, the forest acts as a retainer of heat while the high latitude forest repels what little radiation it has available.

1. JORDAN, Carl F.

2. 1971

3. A world pattern in plant energetics.

4. American Scientist 59:425-433

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree), Climate/growth (direct relationships, latitude)

6. The objective of this study was to find a world wide pattern of terrestrial plant energetics that would provide a basis for calculating the productive potential of land areas of the world. The author used ratios to eliminate variations caused by absolute biomass values and therefore was able to recognize patterns more easily. One ratio used was amount of energy bound in long-lived tissue per year to the amount of energy bound in short-lived tissue per year. Wood production was taken as long-lived tissue and litter fall as production of short-lived tissue.

Two major environmental factors that form somewhat regular patterns are solar radiation and precipitation. All other environmental factors were either the result of one or both of the two major factors and therefore have the same approximate world patterns as the major factors. It was recognized by the author that other factors that do control productivity form patterns so complex that correlation with ecological productivity is impossible because of the limited number of productivity studies. The author also noted that the amount of solar radiation impinging on the plant during the growing season determines the plant's response, not simply the amount per year.

Several patterns were described and discussed by the author. The ratio of wood production to litter production in forests generally increases along a gradient of decreasing solar energy. From the data available, the author suggested that there was no relation between productivity and available solar energy as indicated by latitude and altitude. The variations in wood production were apparently caused by local variations including soil moisture and fertility. On a world wide scale, the absolute rate of wood production in mesic forest areas would be almost constant if variations in such local factors as soil moisture and fertility were eliminated.

In contrast, litter fall values decrease with increasing latitude and/or altitude. Litter fall decreases from approximately 2,000 $g/m^2/yr$ in the tropics to just over 200 $g/m^2/yr$ in north temperate latitudes or on mountain tops. The author's summary of the features of the world pattern of absolute production indicated that along a gradient of decreasing available solar energy, wood production is constant but litter production decreases; along a gradient of decreasing precipitation, litter production is constant but wood production decreases.

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Analysis of world patterns of plant efficiency indicated that communities at higher latitudes and altitudes produce wood more efficiently than communities at lower ones. Efficiencies of litter production might be fairly constant throughout the world, or perhaps even decrease at higher latitudes and altitudes. Litter production in tropical communities was three to five times greater than in northern temperate communities, yet they had available only about twice the solar radiation of communities in the temperate zone. Where precipitation becomes severely limiting to plant growth, efficiency of solar energy utilization tends to be low regardless of amounts of solar energy.

The wood to litter production ratio decreases along a gradient of decreasing precipitation; in temperate zone communities a low ratio is usually the result of a low rate of wood production, not a high rate of litter production. The author hypothesized on the adaptive advantages of high ratios and high caloric concentrations for plants in regions of limited solar radiation. If gymnosperms generally have higher wood to litter production ratios and caloric concentrations than angiosperms, it would suggest why gymnosperms replace angiosperms along a gradient of decreasing solar radiation from the tropics to the taiga, or with increasing altitude in the mountains of mesic regions. The less the available solar radiation within a general region, the greater the advantage of gymnosperms over angiosperms.

The following estimates of wood production and litter production in temperate forests were presented by the author:

Type of community	Location	Wood production $g/m^2/yr$	Litter fall $g/m^2/yr$
Fir	Mid taiga, Russia	450	250
Fir	Southern taiga, Russia	550	300
Fir	Northern taiga, Russia	300	150

The author stressed that before ratio patterns and environmental patterns can be compared, two biological factors must be considered. One factor is that the ratio of wood production to litter production is a function of age of community as well as a function of environment. Even-aged forests (forests composed of trees all about the same age) which are either young or old have ratios lower than those of both intermediate even-aged forests and forests that have trees of all ages. Rate of wood production in young forests could be limited by the cambial area of the trees, causing the ratio in these communities to be low. In communities where most of the biomass occurs in old trees, the ratio also is low. As trees reach old age, their rate of wood production decreases faster than their rate of leaf production.

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The other biological factor that influences the world pattern of wood/litter production ratios is that vascular plants have two basically different structures. In trees and shrubs, energy used as wood is stored mainly above ground. In herbs and grasses, energy used as wood or woody-like tissue is stored below ground. Trees and grasses growing in the same region can be subjected to the same environmental forces and yet have different ratios because of their basically different structure. For this reason, a pattern of ratios in forest communities is considered separately from a pattern in grass and herb communities. In areas where forests and grasslands are intermixed, forests often replace grassland through the process of succession.

1. JUNTTILA, Olavi and Ola M. HEIDE

2. 1981

3. Shoot and needle growth in Pinus sylvestris as relates to temperature in northern Fennoscandia.

4. Forest Science 27:423-430

5. a. Finland, Norway

   b. Scots pine

   c. Climate/growth (direct relationships)

6. Shoot and needle growth of 20-year-old Scots pine trees was studied in relation to temperatures of the current and previous season at three localities (Bardufoss and Alta in Norway and Kevo in Finland) over a ten-year period. Leader length and the number of needle fascicles pr leader had highly significant positive correlation coefficients with the mean June-August temperature of the previous season. A low number of needle fascicles per leader was associated with a high frequency of fascicles with three needles. Needle length showed a significant positive correlation with the mean temperature of the current growing respiration equivalents instead of mean temperatures did not significantly improve correlation coefficients. A highly significant positive correlation was also found between needl lenght and next year's leader growth.

Shoot growth in Scots pine is a two-stage process. Growth phase 1, initiation of stem units and formation of winter buds, occurs in year n; growth phase 2, elongation of the bud, occurs in year n + 1. In the absence of severe stress year in year n + 1, final shoot length is fixed by the number of stem units initiated in year n. In northern areas, summer temperature is often a limiting factor for shoot growth and in northern Fennoscandia shoot growth in Scots pine is closely related to summer temperature of the previous year.

The following parameters were observed in each tree for the years 1968 to 1977: length of annual leader, number of needle fascicles on the leader, and length of ten needles from the middle of the leader. These growth parameters were correlated with each other and with temperature data (monthly mean temperature based on daily temperature readings, and effective heat sum) from meteorological stations at each sampling locality. Effective heat sums were calculated using 4° C as the base temperature.

Correlations coefficients between mean temperature and growth parameters were in most cases as high as those between effective heat sums or respiration equivalents and growth parameters. This was especially true

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for the data from Alta. In other words, the biological temperature dependence was in this case expressed equally well by the mean temperature as by the more elaborately derived expressions of temperature.

Next year's leader growth in Scots pine near the arctic treeline can be predicted in the fall on the basis of the current year's needle length, because both represent integrals of the same heat sum. Photosynthetic surface is increased both with increased needle number and increased needle length. In the present study the year to year variation in needle number was larger than the variation in needle length. Therefore, the observed relationship between needle length and next year's shoot length is not explained by the increased/decreased photosynthetic surface alone. Obviously, direct rate limitations are of greater importance than the indirect temperature effects through photosynthetic area.

The present study was based on observations from natural climatic conditions. The authors indicated that phytotron experiments are now needed to investigate in more detail the relationships between climatic conditions of the previous and current season and the growth of various ecotypes of Scots pine.

1. KABZEMS A., A.L. KOSOWAN and W.C. HARRIS

2. 1976

3. Mixedwood section in an ecological perspective, Saskatchewan.

4. Department of Tourism and Renewable Resources, Forestry Branch, Technical Bulletin No. 8. 118 p

5. a. Canada; Index maps NN-12, NN-13; Saskatchewan; B.18a

   b. Aspen, balsam poplar, black spruce, jack pine, larch, white spruce

   c. Forest growth and yield

6. The Mixedwood Forest Section (B.18a) lies within the prairie provinces of Alberta, Saskatchewan and Manitoba. In Saskatchewan, this section is a band from about 30 to 130 km wide, extending across the province in a southeast to northwest direction between 52° N and 57° N latitude. It occupies approximately 119,736 km^2. Administratively this area is composed of:

1) settlement or agricultural area	36,511 km^2
2) provincial forests and parks	76,449 km^2
3) Indian reserves	2,901 km^2
4) Prince Albert National Park	3,875 km^2

The objectives of this study were: to identify ecological forest units or ecosystems within the Mixedwood Forest Section in Saskatchewan, and to appraise their use in forest management; to provide a better understanding of the ecosystem concept in order to base forestry practices on sound and fundamental ecological principles rather than short term wood volume inventories; to relate consequences of various management alternatives regarding forest establishment, stand development and perpetuation; and to emphasize the land potential for forest production.

Most of the text is made up of detailed descriptions of soils, vegetation and forest productivity in forest ecosystems in each of six soil drainage classes:

1) very rapidly and rapidly drained series
2) well drained series
3) moderately well drained series
4) imperfectly drained series
5) poorly drained series
6) very poorly drained series

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The forest ecosystems recognized by the authors are listed in the table below, along with information on soil drainage, mean annual increment (M.A.I.) and yield at rotation age.

Forest Ecosystem	Drainage	Rot. age (yr)	M.A.I. (m^3)	Yield at rot. age (m^3/ha)
Pinus-Cladonia/Arctostaphylos	Rapid	80	0.9	65
Picea glauca-Agropyron/Arctostaphylos	Rapid	90	1.4	110
Populus-Rosa/Elymus	Rapid	80	1.3	100
Picea glauca/Populus-Corylus	Rapid	80	1.8	140
Pinus-Vaccinium vitis-idaea/Pleurozium	Well	70	2.0	135
Picea glauca-Pleurozium	Well	7[illegible]	3.1	225
Populus-Corylus	Well	70	2.8	185
Picea glauca/Populus-Cornus	Well	75	3.1	210
Pinus-Pleurozium/Lycopodium	Mod. well	65	2.9	180
Picea glauca-Pleurozium	Mod. well	70	4.5	315
Populus-Aralia/Linnaea	Mod. well	60	3.7	225
Picea glauca/Populus-Cornus/Mitella	Mod. well	65	4.3	285
Picea mariana-Pleurozium/Hylocomium	Mod. well	100	1.4	140
Pinus/Picea mariana-Pleurozium	Imperfect	75	1.6	120
Picea glauca/Populus-Cornus/Rubus	Imperfect	75	2.4	195
Picea mariana-Pleurozium/Ptilium	Imperfect	90	2.3	200
Picea glauca-Equisetum	Poor	85	1.6	120
Picea mariana-Pleurozium/Hylocomium	Poor	120	0.9	110
Larix-Picea mariana-Ledum/Pleurozium	Poor	90	1.4	125
Picea mariana-Ledum/Carex	Very poor	130	0.7	90
Picea mariana-Ledum/Sphagnum	Very poor	135	0.6	80
Larix-Carex/Sphagnum	Very poor	100	0.8	80
Larix-Carex	Very poor	130	0.5	65

1. KALLIO, P.

2. 1975

3. Reflections on the adaptation of organisms to the northern forest limit in Fennoscandia.

4. IN: Proceedings of the circumpolar conference on northern ecology, National Research Council of Canada, Ottawa, p. IV-19 - IV-37.

5. a. Finland, Sweden, Norway

   b. Scots pine, Norway spruce, birch

   c. Climate/growth (indirect influences, microclimate, latitude), Climatic change (hypotheses), Treeline studies (growth, climate)

6. A variety of factors that control growth or species distribution in the Fennoscandian subarctic zone are outlined in this paper. For example, a case of indirect climatic influence on the productivity of birch in mountain valleys was given. Thermal inversions of up to 15° C during winter resulted in lower survival of the defoliator, **Oporinia**, in mountain valley bottoms. Defoliation of birch by **Oporinia** the following summer was much less severe in the valley bottoms compared to valley sides above the temperature inversion. In 1966 large areas of birch forests in Fennoscandia were defoliated during an **Oporinia** population peak. The author suggested that natural reforestation would not occur in some of the defoliated areas. This would be at least partly due to changes in local climate, particularly wind velocities and depth of snow cover. Wind damage was noted on junipers which were more than 1,000 yr of age, that had been previously protected by birch forest.

Distribution of Scots pine in the Fennoscandian subarctic is related to warmer local climate, which is often due to topography and sandy soils. Retraction of the pine forest line over the past 2,500 yr was due to a decrease of at least 1.5° C and as much as 3.6° C during the growth period. Vegetatively, pine can survive cool summers, but warm summers are critical for regeneration of pine stands. During the warm period of the 1920's and 1930's, thousands of young pine seedlings established above the present altitudinal treeline. These pine seedlings have since been killed by freezing during dry periods in winter, which is a common ecological eliminator of pine in Fennoscandia.

The adaptation of pine to decreasing energy sum from central Europe to the north correlates well to latitude until near the Arctic Circle. The wide area from there to the northern pine treeline, about 300 to 400 km, is a zone in which trees are not genetically adapted to the average temperature sum. Seed formation is more rare in the zone where pines are poorly genetically adapted; however, seed formation is sufficient to maintain the forest.

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The limits of the main tree species in the Fennoscandian subarctic can partly be understood by different temperature demands. The degree-day demands for growth of Scots pine, Norway spruce, **Betula pendula** and **Betula pubescens** are roughly reflected in their distribution to the north.

Light intensity and day length are reflected in the ecotype formation of northern plants. In Fennoscandia, birch seems to be particularly well adapted to a long day, and can reach positive photosynthesis even in the night during the summer solstice. The light factor is similarly important in the ecotype formation of pine and spruce. The continuous positive net photosynthesis in the Arctic at midsummer is apparently a common type of adaptation to compensate for the short growth period. This kind of adaptation has also been shown in lichens. The author suggested that differing responses to changes in photoperiod in the subarctic be investigated.

1. KARLÉN, Wibjörn

2. 1976

3. Lacustrine sediments and tree-limit variations as indicators of Holocene climatic fluctuations in Lappland, northern Sweden.

4. Geografiska Annaler 58A:1-34

5. a. Sweden, Finland

   b. Scots pine

   c. Climatic change (hypothesis, dendrochronology, proxy data), Climatic variation (regional, temporal, temperature), Treeline studies (growth, climate)

6. Recorded Holocene changes are dated in three different ways: moraines fronting alpine glaciers are dated lichenometrically; lacustrine sediments, in which the silt content varies with size fluctuations of a small glacier are C^{14} dated; and variations in altitude of the pine tree limit are C^{14} dated.

Little is known about the quantitative relationship between temperature variation and the resulting glacier and altitudinal tree limit fluctuations. The author stressed that the exact time lag in the response of the glacier margin and the tree limit to climatic variations is largely unknown. Therefore the dates of glacier and altitudinal tree limit response obtained from the study area do not necessarily correlate exactly with turning points in climatic change. However, the deviation is believed to be relatively small, particularly for the glaciers.

Solar activity and sunspot's are frequently mentioned in discussions about the causes of climatic changes. A certain correlation between the 11 yr sunspot cycle and climate is noted. Links between solar activity and the earth's atmosphere have been suggested, and also a link between variations in the strength of the earth's magnetic field and climate, with a possible parallel reaction to processes in the sun. Even if no definite link between climate, sunspots and solar activity is established, data from this study suggest that cycles in the earth's climate, one of which might be about 180 yr, may exist.

For the purposes of this study, the term 'coniferous tree limit' was used to define the altitudinal line above which only isolated coniferous trees occur. It was assumed that the altitudinal tree limit has moved fairly conformably with changes in climate. Factors such as temperature and its distribution during a year, as well as local topography control the position of the altitudinal tree limit. The altitude above coniferous tree limit is taken as a better point of reference than the altitude above sea level. Postglacial rebound has not been the same in various parts of Scandinavia during the Holocene. It is generally agreed that variations in pine tree limits are caused partly by postglacier rebound and partly by

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changes in climate. However, very little is known about the amount of land uplift, and the climatic influence on the pine tree limit is not necessarily simple. Differences in land rebound between the areas concerned in this study are relatively small compared with other sources of error.

The current altitudinal tree limit depends largely upon average temperature, length of the vegetative period, wind, exposure and slope angle. The tree limit can be depressed locally by forest fires, landslides, snow avalanches and human activity. The climatic parameter most likely to have caused changes in the altitudinal pine tree limit is summer temperature, which in turn depends very much on altitude. The author concluded that land uplift caused a general decrease in tree limit. It is assumed that temperature is an important factor in determining altitudinal tree limit. However, such other parameters as precipitation and wind might have changed and also affected the tree limit. Earlier studies found that pine growth depended directly on summer temperature, and a maximum temperature of at least 17° C during 26 days was required. A more complicated temperature dependence was suggested from studies in northern Finland, where it appears that pine growth requires a mean annual temperature of over -2.5° C, a mean temperature during the June to September vegetative period of at least 8.3° C, and a July mean temperature of at least 12° C.

Glacier fluctuations and altitudinal tree limit variations do not yield detailed information about temperature variations. However, the tree limit variations can be used for an estimate of a minimum mean temperature for warm periods. The results of this study indicate that the pine tree limit has varied within limits of at least 200 m during several intervals within the past 9,000 yr. From lapse rate calculations, it can be deduced that summer temperature has varied by about 1.5° C. It does not appear that the altitudinal pine limit has risen during the relatively warm period of the 20th century, although single trees germinated considerably above the general tree limit during the 1920's and 1930's. Therefore, the climatic variation observed by tree limit variations indicates that the average temperature during a long period, possibly 50 to 100 yr, must have been relatively high.

1. KAY, Paul Allan

2. 1976

3. Post-glacial history of vegetation and climate in the forest-tundra transition zone, Dubawnt Lake Region, Northwest Territories, Canada.

4. University of Wisconsin, Madison, Wisconsin. Ph.D. Thesis. 138 p

5. a. Canada; Index maps NP-12/13, NP-13/14; District of Keewatin, District of Mackenzie; 8.32

   b. Black spruce

   c. Climatic change (hypotheses, dendrochronology, proxy data), Treeline studies (climate, growth)

6. This study reconstructed vegetation and climate of the Holocene for the forest-tundra transition zone in northern Canada. Four sites on a transect from the forest limit to tundra in the Dubawnt River basin were sampled for pollen and dendrochronological data. The distribution of trees is largely determined by climate. The forest limit corresponds to the mean summer position of the arctic front. Pollen and soil studies by other workers have indicated several episodes of forest limit movement during the Holocene.

Trees at the forest limit exhibit larger mean ring widths and lesser sensitivity than do trees in the outliers. The amount of variance in ring widths explained by climate is greater for trees at the forest limit than for trees in outliers. It is suggested that site factors in the outliers mitigate the impact of climatic stress. The results are consistent with the hypothesis of a frontally-determined forest limit.

Included in this thesis was a literature review of relationships between climate and the forest-tundra ecotone. Many workers have attempted to identify the limiting climatic factor. Koppen proposed the 10° C isotherm for the warmest month to differentiate between arctic and boreal forest. Nordenskold reported that the line defined by v = 9° C - 0.1 k (where v is mean temperature for the warmest month and k for the coldest) more closely approximates the forest limit than does the 10° C isotherm. Hare and Ritchie suggested that energy and mass exchanges are the critical factors, and showed that the gradients of some energy parameters (such as absorbed solar radiation, net radiation and length of growing season) intensify somewhat across the forest-tundra transition zone. The Hare and Ritchie approach suggested that the ecotone may correspond to a frontal zone, although the exact connection between energy balance and frontal models has not been made. Reed and Kunkel showed that a belt of maximum frontal frequency corresponds to the boreal-tundra ecotone and Bryson statistically defined an arctic front from surface air mass trajectories, from frequency analysis of daily maximum temperature in July, and from resultant streamline charts of surface winds for each month. He demonstrated that the mean July position of the arctic front

Continued ...

corresponds to the forest limit Barry showed good agreement with Bryson's model in western Canada, but very poor concordance in eastern Canada. The differences probably result from different definitions of the front, from analysis for different levels, and from different periods of analysis. However, Barry showed that the range of positions assumed by the front increased markedly downstream from the Rocky Mountains. Therefore part of the difference between Bryson and Barry probably reflects inherent variability in frontal positions in eastern Canada. Krebs and Barry confirmed a front-ecotone relationship in Eurasia. Hare noted that the ecotone is closely in phase with atmospheric motion - that is, with the position of the arctic jet and the belt of frontal activity: both of these show strong bipolarity, reflecting longitudinal heating inequalities.

The only experimental study of black spruce in the ecotone (Vowinckel et al. 1975) strongly suggests the validity of the frontal hypothesis. The commencement of photosynthesis is determined by a temperature threshold, but the rate of photosynthesis during the growing season is dependent on cloudiness. Increased cloudiness, which reduces photosynthesis and perhaps creates stressful conditions for spruce, might be expected from increased frontal activity. Occurrence of a mean frontal position over a region for a long time might inhibit tree growth and regeneration, whereas further north year-round dominance of arctic air would be inimicable to tree growth. Therefore the frontal zone may be a northward limit to forest extent.

The master tree ring chronologies of this study exhibit episodic and quasi-periodic patterns. No consistent time-transgressive pattern is apparent among the stands. Intervals of below and above-average growth are separated by short transitions. There were times of opposite growth behaviour among the stands. For example, the mid- to late-19th century appears as a prolonged period of poor growth in the outliers, whereas much of the 20th century appears as a period of good growth. A transition towards poor growth appears to have begun in the late 1940's. Superimposed on the episodes are quasi-cyclic variations of about ten year periodicity.

Multivariate analysis indicates that summer temperatures account for one-third to one-half of the variance in the tree-ring indices series. The lack of lengthy climatic records from the study area, however, precluded climatic reconstruction from the tree-ring data. Although summer temperatures explain large amounts of the variance in the tree-rings, they alone are not the most critical parameters for tree growth. Black spruce can carry on photosynthesis even at 0° C. Variables more critical to growth are likely to be length of growing season and amount of solar radiation received. All these variables, however, are related to air mass frequencies and to frontal activity, of which summer temperatures are an index.

Continued ...

Kay, P.A. 1976. Continued

The forest outliers within the tundra are relicts from the former forest cover. They have survived by virtue of their special topographic and edaphic situations. The outliers are insensitive to the kind of climatic stress that might damage trees on upland sites. The threshold for disappearance of widespread forest cover, therefore, is of lesser magnitude than that for removal of all trees. A regional temperature decrease of less than 3 to 5° C may initiate reduction of the forest cover in northern Canada. For the arctic forest limit in the Dubawnt River basin, a mean temperature for July of 11 to 12° C seems to be critical. A decrease of only 1° C, over a prolonged period, may be sufficient to effect movement of the forest edge through a distance of 150 km or more.

The dendrochronological evidence implies that trees at the forest limit have experienced year-to-year temperature variations of amplitude greater than plus or minus 1° C. Changes in mean temperature, however, must persist for a considerable time in order to be effective. The change from forest to tundra at Long Lake (62 38 N, 101 14 W) occurred within two centuries. The occurrence of fires after conditions had become unsuitable for tree reproduction undoubtedly accelerated forest retreat in the study area. A combination of climatic changes - encompassing summer temperatures, precipitation, length of growing seasc and insolation - occurred in response to changes in air mass climatology, of which July temperatures are only a representation. The transition from forest to tundra was probably even more rapid than the two centuries indicated, because of the occurrence of fire in conjunction with many varied climatic stresses.

A threshold for forest readvance is difficult to specify. There is no evidence for forest advance or for outlier expansion in this century, even during the warm period before the 1940's. Climatic thresholds for forest invasion are probably higher than those for forest retreat. Seedling establishment and survival in areas devoid of tree cover perhaps require warmer summers or longer growing season than does maintenance of a population in areas where existing trees afford protection.

1. **KAY, Paul A.**

2. 1978

3. Dendroecology in Canada's forest-tundra transition zone.

4. Arctic and Alpine Research 10:133-138

5. a. Canada; Index map NP-13/14; District of Mackenzie, District of Keewatin; 8.32

   b. Black spruce

   c. Climate (air masses), Climatic change (dendrochronology)

6. The modern coincidence of the closed forest limit with the summer position of the arctic front (Bryson 1966) is the basis for paleoclimatic reconstructions from former forest limits (Sorenson and Knox 1973, Nichols 1967, 1975). Growth in northern trees near their range limit is controlled by thermal stress (Hustich 1966, Larsen 1972), although cloudiness is also a critical limit to photosynthesis (Vowinckel et al. 1975). The mean position of the arctic front marks both a temperature discontinuity and a locus of frequent cloudiness (Hare and Ritchie 1972, Larsen 1965). If mean frontal position changes, then tree growth should be affected, with resultant movement of the forest limit if frontal movement is of sufficient magnitude and duration. This study compared the variability of tree growth and its relation to climate near the northern forest limit.

Trees at the limit of closed forest exhibit more rapid growth, more persistence, and less response to year to year variations in climate than do trees in forest outliers. These features suggest that trees in the outliers are in a more stressful environment than those at the forest limit. The author's data indicate that mild summers and dry conditions (indicating relatively cloud-free conditions) favour wide ring widths, whereas cool and wet (cloudy) summers favour narrow ring widths.

The results of this study are consistent with the hypothesis that the forest limit is controlled by the arctic front. Regional climatic variations account for more of the variance in growth at the forest limit than in the outliers, suggesting that the forest limit is in fine adjustment with the regional climate. If the mean summer position of the front were displaced southward, it is likely that thermal stress north of the front would preclude survival of black spruce on all but the most protected sites. Trees north of the forest limit are more sensitive to high frequency variation in the environment, but are able to persist because the sites they occupy mitigate climatic stress. Outliers are dominated by arctic air masses all year, so frontal variations should not have much effect on growth of trees in outlier areas. The amount of variance in ring widths explained by climate is greater for trees at the forest limit than for trees in outliers.

Continued ...

Kay, Paul A. 1979. Continued

Paleoclimatic reconstruction that assumes a relationship between the arctic front and forest limit therefore seems justified.

The master dendrochronologies from the study exhibit episodic patterns. No consistent time-transgressive patterns are apparent among the stands studied. The intervals of below and above average growth are separated by relatively short transitions. It is suggested that the episodes of poor growth represent periods of frequent summer frontal position south of its average position; good growth periods coincide with frequent northward positions of the front. There is an approximate agreement between the pattern of climate in this study and that established for northwestern North America (Blasing and Fritts 1975). Discrepancies might reflect influence of site factors and/or frontal locations between the study sites.

1. KAY, Paul A.

2. 1979

3. Multivariate statistical estimates of Holocene vegetation and climate change, forest-tundra transition zone, N.W.T., Canada.

4. Quaternary Research 11:125-140

5. a. Canada; Index maps NP-12/13, NP-13/14; District of Keewatin, District of Mackenzie; B.32

   b. Black spruce

   c. Climatic change (hypotheses, dendrochronology, proxy data), Treeline studies (climate, growth)

6. This paper considers patterns of vegetation change within the forest-tundra transition zone in the Dubawnt River basin, and derives associated climatic changes, using newly derived fossil pollen data and multivariate statistical techniques. Study sites extended from Nicol Lake (61 37 N, 103 28 W) northeast to Grant Lake (64 43 N, 100 28 W).

The author concluded that boreal forest extended to approximately 62° N, associated with mean July temperatures 1 to 3° C above modern means, from at least 5500 to 3700 yr B.P. Although a major episode of southward displacement of tree line at about 3700 yr B.P. is recorded, later events are not clearly represented.

The forest limit corresponds to the summer Arctic frontal position, and therefore to steep gradients in air mass frequencies. The forest limit should be more sensitive to change than the vegetational composition of forest or tundra, and should exhibit greater vegetational changes when the front moves. Regions away from the steep gradients of the front should not show as marked changes in vegetation at the same time since they are removed from the critical threshold.

Dendrochronological analysis of black spruce in the study area indicated that a high proportion of the variance in ring widths exhibited by trees at the forest limit was attributable to climate. The registration of change in pollen diagrams from sites away from the front would be further dampened if elements of vegetation persisted out of equilibrium with the regional climate, such as forest outliers amid tundra. The clearly marked discontinuity in vegetation and climate at Long Lake (62 38 N, 101 14 W) indicates that the site was close to the mean summer frontal zone prior to about 3700 yr B.P., and when the mean frontal position shifted southward, the site registered a large change.

The failure of the study sites to register clear evidence of vegetation and climate change after about 3700 yr B.P. might be a result of their distance from, and their resulting insensitivity to, changes at the frontal zone. The possibility of some vegetational change at Nicol Lake about 1000 yr BP, though not detectable at the other sites, might be supported by the relative proximity of Nicol Lake to the frontal zone at that time.

1. KELLOMÄKI, Seppo

2. 1979

3. On geoclimatic variation in basic density of Scots pine wood.

4. Silva Fennica 13:55-64

5. a. Finland

   b. Scots pine

   c. Climate/growth (direct relationships), Growing season (length)

6. The effect of temperature and water supply on the basic density of Scots pine wood was studied on the basis of information obtained from the literature. On a monthly basis, the basic density increased with increasing mean temperature for June, July and August. The rainfall in these months had no detectable effect on the basic density except through the difference between rainfall and evaporation in July. On a yearly basis, the basic density increased with increasing mean temperature, temperature sum and length of growth period. The effect of water supply on the basic density was evident and a linear relationship between basic density and annual rainfall was detected.

Basic density of wood is determined by diameter and wall thickness of tracheids. Both dimensions change during the growing season since earlywood is composed of wide thin-walled cells and the latewood of narrow thick-walled ones. It is generally thought that variations in tracheid wall thickness and diameter are caused by variations of air temperature. In particular, low night temperatures accelerate growth of the tracheid wall.

In summary, both temperature and water supply appear to exert an independent influence on the basic density of Scots pine. Combining these factors, however, yielded an explanatory power of only 40 to 50% of the total variation. This result suggests that there may be other factors, both external and internal, which have a greater effect on basic density than those included in the analysis. For example, the role of the radiation regime was assumed to be of the same magnitude in different parts of Finland during the growing season, but this is not necessarily the case.

1. KELLOMÄKI, Seppo

2. 1979

3. The effect of solar radiation and air temperature on basic density of Scots pine wood.

4. Silva Fennica 13:304-315

5. a. Finland

   b. Scots pine

   c. Climate/growth (direct relationships)

6. The effect of solar radiation and air temperature on the basic density of Scots pine wood was investigated on the basis of material obtained from the literature. Basic density is determined by the diameter and wall thickness of tracheids. Considerable variation occurs in tracheid diameter and wall thickness during the growing season because earlywood is composed of wide, thin-walled cells and latewood of narrow, thick-walled cells. The change in tracheid dimensions with variations in temperature seems to be the main factor controlling cell development in wood.

Radiation in June and temperature in July explained 68% of the total variation in the basic density when applied as independent variables in multiple regression analysis. The weather conditions prevailing in early summer and late summer represented two separate factors, both of which had an effect on basic density. Solar radiation seemed to affect basic density during the formation of earlywood. Temperature had the greatest effect on basic density in late summer. The varying effect of solar radiation and air temperature seemed to be associated with the dynamics of the crown system of the trees. In particular, the capacity of the crown system to produce photosynthate needed in tracheid growth was assumed to be of importance in controlling variation in the basic density of Scots pine wood.

1. KELLOMÄKI Seppo, Pentti HARI and Eero VÄISÄNEN

2. 1977

3. Annual production of some forest mosses as a function of light available for photosynthesis.

4. Silva Fennica 11:81-86

5. a. Finland

   b. Norway spruce

   c. Biomass (moss/lichen)

6. The authors documented annual production of **Pleurozium schreberi**, **Hylocomium splendens** and **Dicranum polysetum** as a function of light available for photosynthesis. These moss species were sampled in several stands representing different density classes situated near the Forest Field Station of the University of Helsinki (60 50 N, 24 20 E, 150 m a.s.l.) in central Finland. All the stands were of the **Myrtillus** site type. The tree stratum of each stand was dominated by Norway spruce.

The total production of the moss cushions was 150 to 180 g/m^2, depending on light conditions. Each of the three moss species produces equal amounts and no clear differences exist, even though the annual production of **Hylocomium splendens** seems to be less than that of the other species. The adaptation of each species to low light intensity is evident since no meaningful addition to production takes place when the photosynthetic light ratio reaches values greater than 30 to 40% of that possible in the open. In particular, the adaptation of **Hylocomium splendens** to low light intensity is evident and decreasing productivity at high light intensities seems to be possible.

1. KELLOMÄKI, S., P. HARI, R. VUOKKO, E. VÄISÄNEN and M. KANNINEN

2. 1977

3. Above ground growth rate of a dwarf shrub community.

4. Oikos 29:143-149

5. a. Finland

   b. Nil

   c. Biomass (shrub/herb), Climate/growth (direct relationships)

6. The aim of this paper was to estimate daily production of structural biomass by means of height growth of plants. Particular attention was paid to the relationship between dry matter production and self regulation of plants and the environment. A method for estimating daily production of biomass was presented for a dwarf shrub community of **Vaccinium myrtillus** (L.) and **Vaccinium vitis-idaea** (L.). The study material was collected from stands of **Picea abies** growing in central Finland (61 51 N, 24 21 E).

The density and above-ground biomass of **Vaccinium myrtillus** and **Vaccinium vitis-idaea** were as follows:

Date of sampling	Species	Density (shoots/m^2)	Biomass (g/m^2)
23 July 1973	**Vaccinium myrtillus**	102	58
	Vaccinium vitis-idaea	47	32
30 July 1975	**Vaccinium myrtillus**	77	2
	Vaccinium vitis-idaea	124	27

In this study, growth was believed to be controlled by temperature and the inherent growth rhythm. The authors' analyses showed the effect of the environment on production of structural biomass, including the effect of density, site fertility, and light conditions. In particular, microvariations in temperature and light patterns inside the field layer can result in uncontrolled variance in productivity measurements because of an unsynchronized growth pattern. In addition, the allocation system of photosynthetic products is not known. As a result, the growth of different parts of the shoots is probably unbalanced.

1. KELLOMÄKI, Seppo, Eero VÄISÄNEN, Pekka KAUPPI and Pertti HARI

2. 1977

3. Production of structural matter by a plant community in successional environment.

4. Silva Fennica 11:276-283

5. a. Finland

   b. Spruce

   c. Biomass (tree, shrub/herb), Climate/growth (indirect influences)

6. Since the growth and development of a plant species takes place only if there is a positive carbon balance, the mutual shading of community members plays an important role in community development. The effect of shading on community development is indicated by the production of structural dry matter by the community members and their share of the total community production. The authors studied net production of a plant community in changing light conditions in order to analyse the successional mechanism of community development. Special attention was paid to above-ground production by ground cover and its succession under control of the dynamics of the crown stratum. Data were gathered at the Forest Field Station of the University of Helsinki in Central Finland (60 50 E, 24 20 N).

The authors found that the grass **Avenella (Deschampsia) flexuosa** is very productive in the first 20 yr during development of a new spruce stand. Thereafter there is a strong decrease in the amount of annual production caused by increasing shading of the tree stratum. Light conditions become crucial for this grass after closure of the canopy. Since the adaptation of **Vaccinium myrtillus** and **Vaccinium vitis-idaea** to low light intensities is evident, closure of the canopy results in an increase in abundance of these two shrub species at the expense of **Avenella flexuosa**.

The calculations carried out in the present study agree with earlier findings on the dominance of herbs and grasses in the initial stages and dwarf shrubs in the late stages of secondary succession. The calculations, however, concern only one part of the succession of spruce stands, the part when growth of spruce has just culminated. Therefore it is evident that the relationship between plant species will change as succession proceeds. In particular, mortality in the tree stratum will decrease crown closure with the result that productivity of plant species in ground cover will increase.

1. KELSALL John P., Edward S. TELFER and Thomas D. WRIGHT

2. 1977

3. The effects of fire on the ecology of the boreal forest, with particular reference to the Canadian North: a review and selected bibliography.

4. Canadian Wildlife Service, Occasional Paper No. 32. 58 p

5. a. Canada; Index maps (all in boreal region); All boreal forest sections in Canada

   b. Nil

   c. Climate/growth (indirect influences), Growing season (length)

6. Although climatic conditions throughout the Boreal Forest Region of Canada - an area ranging from Newfoundland to the Rocky Mountains and Alaska - vary widely, the portion within the Northwest Territories has a relatively uniform climate. There the summers tend to be moderately warm, sunny and dry, and the winters tend to be long and cold. Mean annual precipitation ranges between 25 and 36 cm - only slightly above values typical of true deserts. Of this precipitation, a little less than half falls as snow. Mean annual total snowfall is remarkably uniform, varying between 102 and 127 cm throughout most of the northern boreal forest. Westward of the Rocky Mountains, snowfalls may exceed 150 cm. Many lakes and ponds are present in the northern forest - despite limited precipitation - because the brief summers do not permit massive evaporation and because permafrost, which is widespread in the northern territories, greatly inhibits drainage.

Mean annual minimum temperatures are remarkably uniform at approximately -45° C; somewhat lower minimums occur in the mountainous regions. Maximum summer temperatures vary only slightly above or below 30° C regardless of whether the location is far north of the Arctic Circle in the Mackenzie Delta, at Yellowknife on Great Slave Lake, or further south at Stony Rapids in northern Saskatchewan.

The growing season in the Boreal Forest is short. On its southern fringes in central Ontario and in the middle portions of the prairie provinces, the mean annual length of the growing season is 160 days. In the Northwest Territories the length of the growing season varies from approximately 80 days in the Mackenzie Delta to between 120 and 140 days in areas near 60° N.

Studies by Bryson (1966) have shown that the edge of warm, moist, unstable Pacific air masses pushes northeast in summer to occupy a modal position near treeline at the northern edge of the boreal forest. As winter approaches, the boundary between Pacific and cold, dry, continental arctic air moves south to the southern edge of the boreal forest.

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Kelsall, J.P., E.S. Telfer and T.D. Wright. 1977. Continued

Authorities agree that fire is a natural agent influencing the boreal forest. Some investigators have suggested that this forest is a fire-dependent system that would lose its character, vigour, and faunal and floral diversity in the absence of fire. There is historical evidence of periodicities in weather patterns that would produce periodicities in extent and severity of fires. Thus, long periods of drought tend to coincide with periods of severe fire.

With some exceptions, the forests most subject to burning are those on dry upland sites, where coniferous trees have long been present and where there is an abundance of highly flammable organic litter, dry lichens and mosses on the ground. The decomposition of litter is a slow process in the North, and to some extent fire acts in place of decomposition to return nutrients to the soil and to provide energy sources for new growth. Opinions differ regarding the effects of fire on both nutrients and soils.

The authors cite studies that showed that the highly productive stands of white spruce that flourish on the alluvial soils of the lowlands of the Peace River and the Slave River owe their structure to either a history of fire which prepares suitable seed beds, or to periodic flooding which deposits rich sediments. Similar sequences were reported where large stands of white spruce are present on alluvial soils in Alaska.

Forest succession has been intensively studied both in the northern boreal forest and elsewhere. Although there are general similarities, the mode of succession that can occur in each individual area depends on several factors that include the type of fire, the type of forest burned, presence or absence of permafrost, extent and quality of fuels on the forest floor, presence or absence of suitable seed for forest regeneration, and topography and exposure. Many northern forests do not necessarily revert to deciduous tree species following the burning of conifers. Black spruce in particular tends to be self-perpetuating and to dominate the northernmost boreal forest areas of Canada.

1. KER, M.F.

2. 1973

3. Dry matter production in a young balsam fir stand in western Newfoundland.

4. Environment Canada, Canadian Forestry Service. Newfoundland Forest Research Centre, St. John's, Newfoundland. Information report N-X-103, 31 p

5. a. Canada; Index map NM-21/22; Newfoundland; B.28b

   b. Balsam fir, Black spruce, White birch

   c. Biomass (tree), Forest growth and Yield

6. This report provides biomass data for a 20 year artificially seeded balsam fir stand located near Cormack, Newfoundland, at approximately 49°N, 41°W. Numbers of stems per hectare for various diameter classes are summarized in Table 1 and standing crop (kg/ha) is summarized in Table 2. Excluding roots and cones, the artificially seeded balsam fir stand produced a total of 12053 kg/ha of oven dry matter, distributed as follows: foliage 38.7%, stem wood 32.8%, branch wood 12.6%, branch bark 7.7%, stem bark 7.4%, and dead branches 0.8%.

TABLE 1. Number of stems per hectare for a 20 year balsam fir stand in Newfoundland.

Diameter breast height class (cm)	Number of stems per hectare			
	Balsam fir	Black spruce	White birch	TOTAL
0.60	1584	42	163	1789
2.54	3005	42	339	3386
5.08	1048	15	301	1364
7.62	205	30	193	428
10.16	22	12	32	66
12.70	0	0	17	17

TABLE 2. Dry matter production by above-ground components for a 20 year balsam fir stand in Newfoundland.

DBH class (cm)	0.60	2.54	5.08	7.62	10.16	Total
Stem wood (kg/ha)	246.9	1020.8	1682.4	827.7	169.7	3947
Stem bark (kg/ha)	49.2	276.3	369.6	168.1	33.0	896.2
Branch wood (kg/ha)	96.5	405.4	641.8	312.4	63.9	1520.0
Branch bark (kg/ha)	72.8	243.3	383.3	188.2	38.9	926.5
Foliage (kg/ha)	348.2	1463.9	1846.7	839.3	166.2	4664.3
Dead branches (kg/ha)	3.2	38.9	38.8	14.6	2.5	98.0
Total (kg/ha)	816.9	3448.7	4962.4	2350.9	474.3	12053

1. KER, M.F.

2. 1974

3. Dry matter production in a young black spruce stand in western Newfoundland.

4. Environment Canada, Canadian Forestry Service. Newfoundland Forest Research Station, St. John's, Newfoundland. Information Report N-X-110. 26 p

5. a. Canada; Index map NM-21/22; Newfoundland; B.28b

   b. Black spruce, White birch

   c. Biomass (tree), Forest growth and yield

6. This study provides biomass data for a 21 year mixed black spruce and white birch stand located near Cormack, Newfoundland, at approximately 49°N, 41°W. The black spruce had been artificially seeded, but white birch had regenerated naturally on the study site. The number of stems per hectare, basal area, stem wood volume, and dry matter production for the stand are given in Tables 1, 2, 3 and 4.

The above-ground portion of the stand produced an average of 20,132 kg/ha of black spruce dry matter and 7,396 kg/ha of white birch dry matter. The distribution of spruce production by component was: foliage 38%, stem wood 28%, branch wood 19%, branch bark 10%, and stem bark 5%. The distribution of white birch dry matter was: stem wood 47%, branch wood 25%, foliage 12%, branch bark 9%, and 8% as stem bark.

Table 1. Number of stems per hectare for a 21 year mixed black spruce and white birch stand in Newfoundland.

Diameter breast height class (cm)	Number of stems per hectare		
	Black spruce	White birch	Total
0*	874.7	89.0	963.7
1.27	410.2	113.7	523.8
2.54	1087.2	353.4	1440.6
5.08	971.1	296.5	1267.6
7.62	447.3	173.0	620.2
10.16	59.3	49.4	108.7
12.70	0.0	5.0	5.0
15.24	0.0	5.0	5.0
TOTAL	3849.8	1085.0	4934.6

* stem not yet at breast height

Continued ...

Table 2. Basal area and stem wood volume for a 21 year mixed black spruce and white birch stand in Newfoundland.

Diameter breast height class (cm)	Basal area (m^2/ha)			Stem wood volume (m^3/ha)		
	Black spruce	White birch	Total	Black spruce	White birch	Total
under 1.27	0.0459	0.0229	0.0688	0.2799	0.1469	0.4268
2.54	0.5510	0.1837	0.7347	1.7350	0.7976	2.5329
5.08	1.9750	0.5969	2.5720	5.0310	1.8122	6.8430
7.62	2.0430	0.7806	2.8240	5.2198	2.3400	7.5640
10.16	0.4822	0.4133	0.8950	1.3574	1.3150	2.6730
12.70	0.0000	0.0689	0.0689	0.0000	0.2379	0.2379
15.24	0.0000	0.0689	0.0689	0.0000	0.3149	0.3149
TOTAL	5.0971	2.1350	7.2320	13.6230	6.9690	20.5920

Table 3. Oven dry weights of the black spruce stand component and its distribution by DBH class and tree component for a 21 year mixed black spruce and white birch stand in Newfoundland.

DBH class (cm)	1.27*	2.54	5.08	7.62	10.16	Total	% dist. by component
Stem wood (kg/ha)	47.8	549.7	2129.4	2313.4	563.8	5604.1	27.8
Stem bark (kg/ha)	12.3	121.4	398.9	394.7	90.1	1017.5	5.1
Branch wood (kg/ha)	29.9	358.8	1437.1	1597.9	396.9	3820.7	19.0
Branch bark (kg/ha)	45.0	333.9	835.7	702.4	142.8	2059.9	10.2
Foliage (kg/ha)	125.2	1066.8	3056.1	2783.4	598.6	7630.2	37.9
TOTAL (kg/ha)	260.2	2430.6	7857.4	7791.8	1792.2	20132.4	100.0
% distribution by DBH class	1.3	12.1	39.0	38.7	8.9	100.0	

* 1.27 cm and under.

Table 4. Oven dry weights of the white birch stand component and its distribution by DBH class and tree component for a 21 year mixed black spruce and white birch stand in Newfoundland.

DBH class (cm)	1.27*	2.54	5.08	7.62	10.16**	Total	% dist. by component
Stem wood (kg/ha)	16.8	374.1	1051.2	1237.9	797.4	3477.5	47.0
Stem bark (kg/ha)	4.3	75.1	183.7	198.8	118.5	580.4	7.8
Branch wood (kg/ha)	16.6	261.3	594.0	615.2	352.5	1839.7	24.9
Branch bark (kg/ha)	6.3	93.9	207.2	210.9	119.1	637.3	8.6
Foliage (kg/ha)	13.0	152.3	288.6	268.1	139.5	861.6	11.7
TOTAL (kg/ha)	57.0	956.8	2324.7	2531.0	1527.0	7396.5	100.0
% distribution by DBH class	0.8	12.9	31.4	34.2	20.7	100.0	

* 1.27 cm and under
** 10.16 cm and over

1. KER, M.F.

2. 1980

3. Tree biomass equations for ten major species in Cumberland County, Nova Scotia.

4. Environment Canada, Canadian Forestry Service, Maritimes Forest Research Centre, Fredericton, New Brunswick. Information Report M-X-108. 26 p.

5. a. Canada; Index map NL-20; Nova Scotia

   b. Balsam fir, white spruce, black spruce, jack pine, larch, white birch, aspen

   c. Biomass (tree)

6. In this paper logarithmic equations were given for estimating fresh and dry weights of several tree components for ten common Nova Scotian tree species including balsam fir, white spruce, black spruce, jack pine, larch, white birch and aspen. Although the study area of Cumberland County, Nova Scotia was outside the boreal forest, information for tree species that occur in the boreal forest have been annotated. Separate equations were given for each of 12 biomass variables. In this annotation only the equations for total oven dry above-ground weight (w) are given in the table below in relation to D (diameter at 1.3 m above ground, cm), CW (crown width, m), CL (live growth length, m), or H (total tree height, m).

Component (total above-ground)	Equation (oven-dry weight in kg)	R^2
Balsam fir	$\ln W = -1.8337 + 2.1283 \ln D$	.97
	$\ln W = -1.6768 + 1.8432 \ln D + 0.6113 \ln CW$	.97
White spruce	$\ln W = -2.2662 + 2.2907 \ln D$	.99
	$\ln W = -2.2162 + 2.0782 \ln D + 0.3019 \ln CL$	.99
Black spruce	$\ln W = -1.7823 + 2.1777 \ln D$	.99
Jack pine	$\ln W = -2.2136 + 2.3291 \ln D$	.98
	$\ln W = -2.3637 + 2.1325 \ln D + 0.2779 \ln H$	.99
Larch	$\ln W = -2.3583 + 2.3572 \ln D$	.99
	$\ln W = -2.6227 + 1.8919 \ln D + 0.6154 \ln H$	.99
White birch	$\ln W = -2.2308 + 2.4313 \ln D$	.99
	$\ln W = -2.5938 + 2.1868 \ln D + 0.4031 \ln H$	.99
Aspen	$\ln W = -2.6224 + 2.4827 \ln D$	.99

1. KER, M.F. and G.D. VAN RAALTE

2. 1981

3. Tree biomass equations for **Abies balsamea** and **Picea glauca** in northwestern New Brunswick.

4. Canadian Journal Forest Research 11:13-17

5. a. Canada; Index map NL-19; New Brunswick; 8.2

   b. Balsam fir, white spruce

   c. Biomass (tree)

6. In this article equations are given, based on data from 298 balsam fir and 88 white spruce trees in northwestern New Brunswick (47 51 N, 68 20 W) for predicting oven-dry weight of biomass for balsam fir and white spruce trees. Separate equations are given for each of nine components: stem wood, stem bark, total stem, branches, foliage, total crown, total above-ground weight and total tree. Independent variables used in the equations include diameter at breast height, height, crown width, crown length and indices of basal area, crown area and crown volume.

Weather records for the study area indicate an annual frost-free period of 110 days from May to September, a mean annual temperature of 12° C and an annual precipitation of 106 cm, of which 46 cm falls between June and September. The study stands were primarily even aged, ranging from 5 to 90 yr.

Total above-ground dry weight of balsam fir trees was predicted by:

$$W = 1.1886 + 0.00874\ D^2H - 1.0682\ H + 0.1401\ D^2 + 0.9213\ CL$$

(based on 240 trees, $R^2 = 0.991$)

and root dry weight was predicted by:

$$W = -0.6653 + 0.0660\ D^2$$ (based on 173 trees, $R^2 = 0.863$)

in which W = oven-dry weight (kg); D = diameter at breast height, outside bark (cm); H = total tree height (m); CL = live crown length (m); CW = crown width (m).

For white spruce the predictive equation for total above ground dry weight was:

$$W = -8.1324 - 1.6183\ D + 14.3058\ CW + 0.3399\ D^2 - 3.8395\ CW^2$$

(based on 70 trees, $R^2 = 0.969$)

and root dry weight was predicted by:

$$W = 1.2299 - 0.4843\ H + 0.0882\ D^2$$ (based on 59 trees, $R^2 = 0.959$)

with W, D, H, and CW as defined above for balsam fir.

1. KJELVIK, S. and L. KÄRENLAMPI

2. 1975

3. Plant biomass and primary production of Fennoscandian subarctic and subalpine forests and of alpine willow and heath ecosystems.

4. IN: P.E. Wielgolaski, Editor, Fennoscandian Tundra Ecosystems, Part 1. Plants and Microorganisms. Springer-Verlag, New York. p. 111-120

5. a. Finland, Norway

   b. Pine, birch

   c. Biomass (tree, shrub/herb, moss/lichen), Climate/growth (latitude)

6. This paper describes the results of studies of plant biomass and primary production of subarctic and subalpine forests in Hardangervidda, Norway and Kevo, Finland conducted during the International Biological Programme (IBP).

The biomass (. ve material) and standing crop (live + dead material) of pine and birch in the Finnish and Norwegian forest sites were as follows:

	Pine Kevo (kg/ha)	Birch Kevo (kg/ha)	Birch Hardangervidda (kg/ha)
Stem wood	13,897	3,530	13,940
Stem bark	2,010	1,587	3,390
Stem total	15,907	5,117	17,330
Leaves	2,314	595	970
Attached dead leaves	427	-	-
Attached dead twigs	1,783	1.2	300
Living branches	8,759	1,782	4,770
Dead branches	1,395	85	131
Cones	743	-	-
Dead basal shoots	-	833	399
Roots	7,324	3,541	11,340
Total tree biomass	35,047	11,035	34,310
Total tree standing crop	38,650	12,075	35,140

Continued ...

Average standing crops of understory vascular plants for three study sites at Hardangervidda were as follows (g/m^2, dry weight):

	Above-ground standing crop					Roots live	Roots dead	Total alive
	Green			non-green	dead			
	Min.	Max.	Mean					
Birch forest	54.7	142.2	102.0	89.5	153.3	633.7	205.7	825.1
Willow thicket	6.4	69.9	41.5	30.9	121.1	880.7	46.8	953.2
Lichen heath	15.5	34.2	26.9	34.1	151.3	190.7	125.3	251.7

Total standing crops of understory vascular plants for the study sites at Kevo were as follows (g/m^2, dry weight):

Sites & species	Total leaves*	Total stems	Standing dead	Roots	Fruits	Total alive
Moist birch forest	41.2	153.3	62.7	487.0	25.1	706.5
Main IBP birch forest	48.8	184.3	55.4	514.6	7.0	754.5
Oporinia-damaged birch forest	54.0	151.1	44.2	628.0	3.3	836.4
High elevation birch site	15.5	135.2	72.1	213.1	10.4	374.2
IBP pine forest	50.2	60.5	21.8	280.8	0.5	392.1
Low alpine heath	28.1	147.6	61.9	195.2	4.0	374.8

* Leaves and stem were not separated in Empetrum

Total standing crops of mosses and lichens for the study sites at Kevo and Hardangervidda were as follows (g/m^2, dry weight):

Kevo	Moist birch forest	Birch forest	High elev. birch	Pine forest	Low alpine heath
Altitude (m)	131	130	320	115	330
Total mosses (g/m^2)	39.4	33.2	62.6	18.0	7.2
Total lichens (g/m^2)	58.1	19.2	73.7	84.5	77.2
Total mosses & lichens (g/m^2)	97.4	52.4	136.3	102.4	84.5

Hardangervidda	Birch forest	Willow thicket	Lichen heath
Altitude (m)	780	1,250	1,220
Total mosses (g/m^2)	61.1	307.2	6.7
Total lichens (g/m^2)	9.3	0.0	382.3
Total mosses & lichens (g/m^2)	70.4	307.2	389.0

Continued ...

The willow thicket site had a higher total understory (vascular plants plus mosses and lichens) biomass than the heath sites or the understories of the forest sites. The good moisture status and high nutrient content of the soils present in the willow thicket were suggested to be the reason.

The live biomass of primary producers at each of the study sites can be summarized as follows (kg/ha, dry weight):

	Kevo			Hardangervidda		
	Pine forest	Birch forest	Low alpine heath	Birch forest	Willow thicket	Lichen heath
Pine	29,859	-	-	-	-	-
Birch	400	11,035	1,261	34,310	-	-
Other bushes	-	200	-	2,165	11,276	-
Ground vegetation:						
vascular	3,921	7,545	3,748	8,252	9,532	2,517
mosses	180	332	72	611	3,072	67
lichens	845	192	772	93	0	3,823
Total	35,205	19,304	5,853	45,431	23,880	6,407

Plant production estimates on an annual ($g/m^2/yr$, dry weight) and daily ($g/m^2/day$, dry weight) basis are given below for the understory of different vegetation types at Hardangervidda:

	Willow thicket		Birch forest		Lichen heath	
	Annual	per day	annual	per day	annual	per day
Vascular plants understory green	173	1.7	267	2.1	72	0.6
Non-green above first root	31	0.3	80	0.6	13	0.2
Roots	220	2.2	110	0.8	97	0.9
Subtotal vascular plants understory	424	4.2	457	3.5	182	1.7
Trees and shrubs	250	2.5	283	2.2	-	-
Cryptogams	210	2.1	40	0.3	88	0.8
Total	884	8.8	780	6.0	270	2.5

Continued ...

Primary production of understory vascular plants at the Norwegian sites was highest at the willow thicket and lowest at the lichen heath. The production at the sites studied was believed to be strongly correlated with water and soil nutrient content. Total production followed the same pattern. Understory production at the Finnish sites was highest at the birch forest sites, with about 110 $g/m^2/yr$. About as high a production was calculated for the high elevation birch site, the pine forest site and the low alpine heath site. The higher production observed at the Hardangervidda sites may partly be caused by the more detailed calculation method used, and partly by the moisture and nutrient conditions. The precipitation was higher at Hardangervidda than at Kevo and nutrient conditions generally better.

The most luxuriant birch forests in Finland have almost as high maximum tree biomass as found in the Finnish pine forest. The annual production of trees and bushes in the Norwegian birch forest site is almost 2.8 t/ha/yr. In the Norwegian willow thicket and birch forest a yearly growth of 3.1 t/ha/yr of leaves is produced. Using this value and the measured yearly litter fall at Kevo, an average production of 1.4 t/ha/yr in the pine forest and 1.8 t/ha/yr in the birch forest is estimated.

1. KNAPP, Rüdiger

2. 1965

3. Vegetation der Zonen der borealen Nadelwälder Nordamerikas [The vegetation of the boreal coniferous forest areas in North America].

4. IN: Die vegetation von Nord-und Mittelamerica und der Hawaii-Inseln. [The vegetation of north and central America and of the Hawaiian Islands], Chapter 3, Gustav Fischer Verlag, Stuttgart, p 72-89, unedited translation by Translation Bureau, Department of Secretary of State, Ottawa.

5. a. Canada, Alaska; Index maps (all in boreal region); All boreal forest sections in Canada

   b. Nil

   c. Climate (precipitation, temperature), Climatic change (proxy data), Climatic variation (regional), Treeline studies (climate)

6. Included in this description of the boreal forests of North America are descriptions of climatic conditions within the boreal forest area. Generally mean July temperatures are less than 17° C, but usually exceed 10° C. Mean January temperatures may vary considerably within different regions of the boreal forest, ranging from -12° C in the southeastern portions to below -30° C near Great Bear Lake. Precipitation is greatest in the southern portions of the North American boreal forest, approaching an annual mean of 1,000 mm. Near Great Bear Lake, boreal forest occurs in areas having a mean annual precipitation of less than 350 mm. Due to low temperatures and the resulting lack of evaporation, the climate is damp throughout the entire boreal forest area. The bulk of precipitation occurs in summer, except in southeastern Labrador where winter precipitation is dominant.

In general the northern treeline approximately corresponds to the July isotherm of 10° C. During the last few centuries considerable shifts in the northern treeline have occurred. In Alaska, the forest boundary has advanced northward. The evidence to support this hypothesis is as follows: all trees at the forest limit are less than 100 yr old, whereas 4.5 km south of the limit, there are tree trunks of more than 1 m thickness and over 300 yr of age; many old trees within the present forest now grow in closed forests but display growth shapes indicating a formerly isolated position; in early historical reports certain areas are described as treeless, whereas at present they have a dense forest cover; pollen analyses from bogs seem to indicate that the modern forest at treeline is the first forest present since glaciation.

In Labrador and along the lower Coppermine River, there are indications that climate has deteriorated and arctic plant communities have spread at the expense of forests. In the area east of Athabasca and Great Slave lakes the forest limit appears to have remained stable.

1. KOMIN, G.E.

2. 1973

3. Effect of climatic and phytocenotic factors on the increment of trees in stands.

4. Soviet Journal of Ecology 4:54-61

5. a. U.S.S.R.

   b. Nil

   c. Climate/growth (direct relationships, indirect influences)

6. Since the beginning of the 20th century the annual increment of trees has been used widely as an index of climatic variations in past years. Most studies on dendrochronology were performed on the basis of analyzing the increment of the thickness of trees that grew singly or in open stands, where the phytocenotic effect of the trees on one another was usually insignificant. The presence of widely spaced trees is especially characteristic for regions not favourable for the growth of trees, such as in the forest-tundra zone and the upper limit of forest in mountains. Under such conditions the increment of trees is determined to a considerable extent by annually varying factors, primarily climatic.

Singly growing trees are rather rare in regions of the continuous distribution of forest. If such trees are found, investigators cannot always be certain that they grew the entire time outside a stand. The increment of individual trees that grew in dense stands is due not only to climatic variations but also to edaphic and phytocenotic influences. As a consequence, the annual increment of trees from dense stands conveys less reliable information on climatic factors than the increment of trees that grow in open stands or singly.

The increment of trees is affected also by various external agents that disturb the normal development of stands, including windfall and attacks by insect pests. Disturbance of the normal dynamics of the increment of stands can occur also under the effect of natural succession of species.

The author concluded that dendroclimatological investigations of the increment of trees from fully stocked stands cannot give satisfactory results. However, in regions of continuous forests there are many stands in which the growth dynamics of trees are determined to a greater degree by climatic than phytocenotic factors. These are stands that develop without the effect of any external forest-destroying agents and in which processes leading to disturbance of normal growth and development of the stands were not observed in the past. The increment of such stands is identical in many respects to the increment of singly growing trees, and in such stands the annual growth is determined mainly by climatic variations.

1. KORCHAGIN, A.A. and V.G. KARPOV

2. 1974

3. Fluctuations in coniferous taiga communities.

4. IN: R. Tüxen, Editor in Chief, Handbook of Vegetation Science. Part VIII, Vegetation Dynamics, (R. Knapp, Ed.), Dr. W. Junk b.v., Publishers, The Hague, Netherlands. p 225-231

5. a. U.S.S.R.

   b. Nil

   c. Climate/growth (direct relationships)

6. The authors point out that a slight expression of seasonal phenological variation of both evergreen coniferous trees and dwarf shrubs is characteristic of typical taiga forests. Still less pronounced in the coniferous taiga are variations from year to year (fluctuations), associated with different yearly variations in meteorological conditions (precipitation, temperature) although the range of the latter, as well as that of the variations of soil factors (moisture, aeration, mineral regime) is rather wide. The communities of boreal coniferous forests are apparently rather stable systems, well adapted to considerable variations, from year to year, of meteorological conditions and regimes of the soil. In particular, the Hylocomium-dominated vegetation types in boreal coniferous forests are more stable and characterized by a slighter response to the differences in environmental conditions between different years than are the nemoral-type forests of the mixedwood forest zones further south; the latter are more complex than the boreal forests, both floristically and ecologically.

However, if variations in meteorological conditions do not significantly influence either the proportions of different species or the structure of the tree stand, they do affect very conspicuously such characteristics as the growth rate of trees and of plants of the lower layers, the degree of foliage development, density of the canopy, dates and duration of separate phenological phases, and also reproduction of plants by seeds.

The authors state that fluctuations of the growth-rate of trees and of the plants of the lower layers are inherent in all communities of the coniferous taiga. However, in different types of forest and in different phytogeographical zones the range of the fluctuations of the increment of trees can be very wide, with deviations from long term means attaining 50 to 150%. The periodic fluctuations in abundance of spruce seedlings and the recognizable "waves" in their appearance and death are typical of spruce forests. This periodicity is based on complicated relationships between the seed yield of stands, annual variations of the main meteorological factors, and physiological processes in trees. The authors observed that the rhythms of seasonal development also vary depending on meteorological conditions. In years with a cold and protracted spring, the beginning of the vegetative period is shifted to later dates in many tree species.

1. KOVDA, V.A.

2. 1976

3. The problem of biological and economic productivity of the earth's land areas.

4. Soviet Geography 12:6-23

5. a. U.S.S.R.

   b. Nil

   c. Biomass (tree, shrub/herb, moss/lichen)

6. The author estimated the entire terrestrial biomass, including both vegetation and mammals, of the earth. The author noted that economic productivity is closely related to biological productivity. Usually the greater the biological productivity, the higher the economic productivity will be, although there are exceptions and even inverse relationships between these two measures of productivity.

The estimated biomass of some terrestrial landscapes were as follows:

Zones and landscapes	Phytomass (t/ha)	Zoomass (t/ha)	Total biomass (t/ha)	Total biomass of the zone or landscape (t)
Tundra	28.25	0.01	28.26	165×10^8
Southern taiga				
forest	358.6	0.36	358.96	$4,630 \times 10^8$
floodplain	36.2	0.66	36.86	* 157×10^8
fields	14.9	1.68	16.58	12.8×10^8
Chernozem steppe	25.6	1.44	27.04	64×10^8
Sierozem desert	5.3	0.22	5.52	76×10^8
Tropical forest	524.0	4.50	528.50	$5,273 \times 10^8$
				$10,377 \times 10^8$

* Total biomass estimated for all floodplains of the earth.

Scientists have questioned how long biomass exists and what is the average duration of its complete turnover. If one assumes that total terrestrial biomass amounts to 3×10^{12} t and that photosynthesis annually produces an average of 0.016×10^{12} t, or 0.5% of the biomass, then complete renewal of biomass would require about 200 yr.

1. KRAUSE, H.H., G.F. WEETMAN and P.A. ARP

2. 1978

3. Nutrient cycling in boreal forest ecosystems of North America.

4. IN: C.T. Youngberg, Editor, Forest Soils and Land Use, Proceedings of the Fifth North American Forest Soils Conference held at Colorado State University, Fort Collins, Colorado. p 287-319

5. a. Canada; Index maps (all in boreal region); All boreal forest sections in Canada

   b. Black spruce

   c. Climate/growth (direct relationships, indirect influences)

6. This paper is a review of information from within the North American boreal forest and its fringe areas immediately to the south. The objective was to review the main characteristics of nutrient cycling within boreal forest ecosystems, and to draw comparisons to similar processes in forests of more temperate regions. Furthermore, an attempt has been made to evaluate the impact of man's activity on nutrient cycling and productivity in boreal forest ecosystems. The authors indicated that information is limited at present because only few comprehensive studies have dealt with the North American boreal forest. The boreal zone has been subdivided into three parts: a closed-crown forest in the south, a subarctic open lichen-woodland in the centre, and a mosaic of forest and tundra patches in the north. This paper dealt with the closed-crown boreal forest only. In closed boreal forests, average cutting yields range from 75 to 125 m^3/ha, with a generally declining productivity from the climatically more favourable eastern regions in Quebec to the regions of more severe climate west of the Ontario-Manitoba boundary.

The climate in the closed-crown boreal forest varies from moderately cold and perhumid with mean annual soil temperatures of 2° to less than 8° C, less than 220-day growing season, and no significant moisture deficit in the east to very cold and humid with mean annual soil temperatures from -7° to less than 2° C, less than 120-day growing season, and a slight moisture deficit in the west.

The simple structure of boreal forests, relative to forests of temperate zones, has aided in the establishment of easily recognizable relationships between vegetation types, soil fertility, and associated rates of nutrient cycling. In the classification of boreal forests on a phytosociological basis, nutrient-rich sites are associated with an abundance of herbaceous vegetation, sites of intermediate quality with a feather moss or ericaceous cover, and poor sites with lichens if dry and sphagnum mosses if wet.

Continued ...

Residence times of organic matter in the forest floor of several boreal forest types were summarized as follows:

Type	Stand age (yr)	Organic matter residence time (yr)
Jack pine	30	7.4
Black spruce	55-60	27.3
Balsam fir	65	14.0
Aspen	50	17.8
Aspen	120	26.6

The slow rate of organic matter decomposition and nutrient release in boreal forest ecosystems is generally attributed to low mean annual soil temperatures. Respiration rates have been shown to be directly related to soil temperature and net mineralization of N in forest floor samples from a Norway spruce ecosystem also showed a strong dependence on temperature. Increasing the soil's heat budget as for instance by thinning of forest stands may significantly stimulate N release under boreal climates. Litter decomposition is not only affected by temperature but by a combination of environmental factors and substrate quality. Excess water, for example, impairs the activity of arthropods. As a result, excessive amounts of organic matter build up over poorly drained soils to form a greasy mor. The mixing action of earthworms is absent in most boreal forest ecosystems due to high soil acidity and a lack of palatable food materials.

Despite the slow decomposition rates, the forest floor is the location where trees of boreal forest ecosystems derive a major fraction of the annual nutrient demand. Other investigators estimated an annual N release of 14 kg/ha in the forest floor under jack pine. This amount would have provided 54% of the N consumed by the 30-year-old stand. That the organic surface stratum is a major location of nutrient absorption is strikingly illustrated by the distribution of tree roots and nutrient concentrations in soil under a balsam fir stand. More than 50% of the total mass of tree roots less than 1 cm were located in the F and H layers, 25% in the illuviated B horizon, and 17% in the transitional B horizon. Only a very small remainder was found in the eluviated A and in the C horizon.

In the North American boreal forest, ecosystems with dry, sandy and rocky soils of low fertility, and with forest floors of low biological activity appear to be susceptible to lasting disruption of nutrient cycles by heath degeneration. Principal changes in nutrient cycling may also occur

Continued ...

Krause, H.H., G.F. Weetman and P.A. Arp. 1978. Continued

where clear-cutting of forest leads to a rise in the water table with subsequent invasion of sphagnum mosses and sedges. This process has been referred to as paludification.

An outstanding feature of boreal forest ecosystems is the prominence of the forest floor as a major nutrient pool. The reserves of nutrients in organic surface layers are in many instances several times larger than the amounts contained in the standing tree biomass of middle-age and mature stands. Decomposition rates and release of structurally combined nutrients such as N and P are slow because of low mean annual temperatures and unfavourable substrate composition. The rates of nutrient cycling and associated site fertility are thus closely related to the biological controls of organic matter decomposition and accumulation in the forest floor.

Boreal nutrient cycles are tight, unless changed by a disturbance; but even then, losses appear to be small. On most sites, pioneering vegetation establishes itself rapidly after cutting or fire to act as a sink for excessive accumulation of mineralized nutrients. The lesser vegetation may assume special roles in nutrient cycling. Feather mosses seem to aid decomposition of tree litter and N release. In extreme cases, their rhizogenous surface mat may prevent regeneration of forest species and exchange of nutrients between the organic surface layer and the mineral soil.

Present information on nutrient cycling makes it clear that improvement of the currently low productivity in boreal forest ecosystems cannot be achieved without measures leading to a control of forest floor processes. Important considerations are species selection, length of rotation, and stand density. Fertilization not only can temporarily offset N deficiency, but also may change trends in forest floor development. Utilization of the nutrient reserves from the old forest floor by the next tree cover may be controlled by skilled use of mechanical equipment, fire, and herbicides.

1. KREBS, J.S. and R.G. BARRY

2. 1970

3. The arctic front and the tundra-taiga boundary in Eurasia.

4. Geographical Review 60:548-554

5. a. U.S.S.R.

   b. Nil

   c. Climate (air masses), Treeline studies (climate)

6. There is apparently a relationship between the tundra-taiga boundary and the median location of the arctic front in Eurasia.

The authors' analyses showed that the median location of the arctic front in July corresponds closely to the tundra-taiga boundary in the west and to the middle portion of the forest-tundra ecotone in the east. There is generally a rather small spread in terms of quartiles - about 10° of latitude in the west and only 6° to 7° of latitude in the east. This differs markedly from the situation in North America, where the central 50% of the distribution extends over some 13° to 14° of latitude between 40° W and 80° W. The cor -ast may be related to the occurrence in July of a mean trough in the tropospheric flow pattern situated near 70° W. Over eastern Asia at this season the contour pattern is more or less zonal. The situation over eastern North America permits greater latitudinal variability of depression tracks and of the frontal zone as a result of depressions moving with large northward or southward swings on the eastern and western limbs, respectively, of the upper trough. Longitudinal displacements of this trough make the meridional movements of depressions effective over an extensive sector.

The authors state that these findings lend considerable weight to the hypothesis advanced by Bryson (1966), although a more thorough analysis of air mass trajectories and temperature characteristics, or of streamlines, is necessary to confirm the actual frontal location. The region immediately east of the Ural mountains presented the most difficulties because in that area there is commonly a reorganization of the eastward-moving maritime fronts and the southward-moving arctic fronts, and such air-mass modifications restrict the value of data from certain meteorological stations. Further investigations were suggested to determine the precise nature of interactions between vegetation cover at treeline and various properties of the atmosphere.

1. KUBIN, Eero

2. 1977

3. The effect of clear cutting upon the nutrient status of a spruce forest in northern Finland (64° 28' N).

4. Acta Forestalia Fennica 155:1-40

5. a. Finland

   b. Norway spruce, Scots pine

   c. Biomass (tree), Growing season (length, degree day totals)

6. The purpose of this paper was to determine the proportions of nutrients remaining in the forest and nutrients removed as a result of cutting. Surface logging waste was studied in detail in the categories of tree-top waste, branches, twigs, needles and cones. The figures reported for the volumes of harvested bole wood were converted to weight on the basis of the basic density of wood, while the amount of stump and root material was estimated from the known amount of bole wood.

The study area was within an experimental forest at approximately 64°N, 27°E. Climatic parameters from two meteorological stations nearest the study area are given as follows:

Climatic parameters	Kajaani	Vaala
Mean annual temperature (°C)	1.9	2.2
Growing season (days)	149	149
Effective temperature sum (degree days)	1033.0	1050.7
Annual rainfall (mm)	564	525

Mensurational data for the study area are as follows:

Stand age	137 years
Norway spruce volume	110.5 solid m^3/ha
Scots pine volume	4.5 solid m^3/ha
Deciduous pulpwood species volume	0.8 solid m^3/ha
Average diameter at stump height	20.6 cm

Distribution of aerial phytomass into marketable bole wood and waste wood for the 137-year Norway spruce stand in northern Finland is summarized in Table 1.

Continued ...

Table 1. Distribution of above-ground phytomass in a 137-year Norway spruce stand, Northern Finland.

Component	Phytomass, kg/ha
Marketable bole wood (total)	48,618
Sawlogs	32,150
Pulpwood	10,877
Sawlog bark	3,973
Pulpwood bark	1,618
Wastewood (total)	34,748
Tree-top waste wood	2,305
Tree-top waste bark	654
Branches (wood)	14,743
Branches (bark)	6,444
Twigs with bark	3,041
Needles	6,888
Cones	673

Estimated underground phytomass, including stump, for a 137-year Norway spruce stand in northern Finland is summarized in Table 2.

Table 2. Distribution of below-ground phytomass in a 137-year Norway spruce stand, northern Finland.

Component	Phytomass, kg/ha
Stump and root material (total)	22,000
Stump wood	4,700
Roots 5 to 20 cm (wood)	8,800
Roots 1 to 5 cm (wood)	3,300
Stump bark	500
Roots 5 to 20 cm (bark)	1,300
Roots 1 to 5 cm (bark)	2,100
Roots 1 cm with bark	1,300

Aerial, underground and total phytomass for a Norway spruce stand, northern Finland can be summarized as follows:

Aerial phytomass	83,400 kg/ha
Underground phytomass	22,000 kg/ha
Total phytomass	105,400 kg/ha

1. KULLMAN, Leif

2. 1981

3. Some aspects of the ecology of the Scandinavian subalpine birch forest belt.

4. Wahlenbergia 7:99-112

5. a. Sweden, Norway, Finland, Iceland, Greenland, U.S.S.R.

   b. Birch, Scots pine, Norway spruce

   c. Climate/growth (indirect influences, latitude), Climatic variation (regional, temporal), Treeline studies (growth, climate)

6. This paper synthesizes present knowledge about certain ecological aspects of the Scandinavian subalpine birch forest belt. The primary reasons for an altitudinal birch belt are the amount of snow, its duration, and the way in which it disappears in spring and early summer, although the local topographic factors and human impact can influence local distribution patterns. Temperature is important through its influence on thickness, extent and duration of the snow cover.

During the period 1920 to 1950, Scandinavia and the entire northern hemisphere experienced a great increase in the frequency of unusually warm summers. The altitudinal timberline rose several tens of metres during this time, and the birch forest increased in density in places where snow cover today is normally abundant and late in thawing. In areas with a shallow snow cover, which disappears early in spring, no general displacement of the altitudinal timberline was recorded. Studies demonstrated that an intimate relation exists between the amount and duration of snow cover and the vertical extent and density of the subalpine birch forest belt. In districts which are normally snowy, the slopes as a rule have relatively broad and dense birch belts. Temporal changes in wideness of the belt and density of the stands are closely related to fluctuations in summer mean temperature. In most cases on slopes with a shallow snow cover, the birch belt is incomplete and reacts little, if at all, to annual variations in snow cover.

After a review of factors decisive for the reproduction of birch from seed at the altitudinal timberline, the author concluded that successful reproduction demands a moderate but constant supply of soil moisture and a fairly high temperature of the surface soil layers. On a large scale such conditions are frequently encountered at relatively high altitudes where late thawing of the snow maintains a constant supply of soil moisture during summer. Too late thawing excludes birch since the influence of the cold meltwater supply is of too long duration and soil temperatures remain too cool.

Continued ...

Birch foliage is regularly attacked by caterpillars of the moth, **Oporinia autumnata**. Under certain topographical conditions the moth eggs do not survive the winter because of the presence of stagnant and very cold air masses during long periods. The lack of disturbance may contribute to the fact that the bottoms of certain long valleys are practically devoid of arboreal vegetation, whereas the valley sides and mountain slopes are covered with dense forest for several hundred metres above the valley floor. Such phenomena are often attributed to the direct unfavourable influence of low winter temperature on reproduction or growth of birch. The author suggests that this interpretation is less probable since birch is not thought to be particularly sensitive to low winter temperatures. There are indications that birch stands growing on moist snow slopes are especially prone to **Oporinia** attacks. Furthermore, in this type of environment the vegetation in general is very unstable, because climatic changes can very quickly alter the ecological conditions here via changes in snow cover.

Birch is well adapted to survive the snowy and unstable alpine environment. During periods of unfavourable climate, birch can persist vegetatively, only perishing in the most marginal sites. When the climate improves it is capable of recolonizing areas very quickly by seed. Scots pine possesses none of these adaptations. This has probably contributed to the long term retreat of the altitudinal tree limit of pine, which is still progressing in certain parts of the Scandinavian mountains. Norway spruce is able to regenerate vegetatively and the author suggests that this species is showing signs of a slow advance rather than a retreat.

It has been thought that the phenomenon of frost drought is the major obstacle to tree growth above a certain altitude. Recent studies have shown that this is the most important fact for many evergreen conifers. However, frost drought does not seem to influence birch. Damage has not been noted on birch when nearby conifers suffered extensive frost drought damage. In Greenland, studies indicated that birch was able to transport water from deeper unfrozen soil levels, through the superficial frozen soil layers. If this result is correct and generally applicable, then it represents a very advantageous adaptation to the hazard of frost drought on snowy high altitude sites where soil usually freezes just beneath the surface, if at all.

1. LAAKSONEN, Kyösti

2. 1979

3. Effective temperature sums and durations of the vegetative period in Fennoscandia (1921-1950).

4. Fennia 157:171-197

5. a. Norway, Sweden, Finland

   b. Nil

   c. Climate (temperature), Climate/growth (direct relationships, latitude), Climatic variation (regional, temperature), Growing season (length, degree-day totals)

6. In this paper, data are presented in tabular and map form, for the beginning, end, duration and effective temperature sum of the vegetative period for Fennoscandia. The vegetative period denotes the duration of daily mean screen air temperatures of 5° C or more calculated from observations from 598 stations over a period of 30 yr (1921-1950). Values representative of their geographical location are calculated by making the following corrections to the values presented on the maps; altitude, lake effect, urban effect and relative altitude.

On the basis of the data it is possible to perform general comparisons within extensive areas and detailed local comparisons within relatively small areas. The data presented in the maps represent general average conditions and are not applicable to individual years. Since the fjord belt in Norway is extremely broken, with very marked local variations in its mean air temperatures, it was impossible to construct generally applicable isopleths to that coastal area.

On the Atlantic coast of Vestlandet, western Norway, the vegetative period is very long, but cool. In southern Finland, however, the vegetative period is much shorter, but here midsummer is much warmer than in Vestlandet. Thus, neither the duration of the vegetative period nor the warmth of mid-summer alone are sufficiently valid indicators of the advantage of the vegetative period. When both the warmth and the duration of the vegetative period are simultaneously taken into account, a more valid indicator is obtained, and the effective temperature sum (ETS) can be regarded as a useful thermic indicator for many purposes. ETS expresses the sum obtained by subtracting 5° C from the mean temperature of each day that has a mean temperature above 5° C, and then adding all the individual daily surpluses.

The following factors tended to reduce the length of the growing season or decrease the effective temperature sum: proximity to cold seas, strong advection of cold air from adjacent seas, locally dense cloud cover, and abundant snow cover. The following factors lengthened the duration of the vegetative period or increased the effective temperature sum: warm seas or sea currents, reduced advection of cold air from the sea, and reduced cloud cover.

1. LaMARCHE, Valmore C., Jr.

2. 1978

3. Tree-ring evidence of past climatic variability.

4. Nature 276:334-338

5. a. Northern hemisphere

   b. Nil

   c. Climate/growth (direct relationships, latitude), Climatic change (dendrochronology, proxy data)

6. This paper is a general discussion of the use and techniques of tree-ring evidence for determining past climatic variability. The basic premise underlying the interpretation of ring width variations in climatic terms is that climatic factors can directly or indirectly limit growth processes in trees. The most suitable trees, with climatically sensitive ring series, are often found in marginal situations, such as at the northern treeline, at the upper treeline in the mountains of temperate latitudes, near the arid forest border in desert regions, or as suppressed understory trees in temperate forests. Under such circumstances, in an adverse year, one or more environmental factors such as soil moisture content, air temperature or sunlight may frequently limit biological processes such as photosynthesis that are essential for development of an annual ring of normal width. Because all the trees in the same area experience the same general weather conditions, all those in appropriate ecological situations will form narrower than usual rings in a bad year. The resulting synchronous sequences of wide and narrow rings provide the basis for crossdating of tree-ring series as well as for paleoclimatic inferences.

The simplest approach to paleoclimatic reconstruction with tree-ring data is to use a highly stratified sample from trees responding in a simple manner to a single dominant climatic variable, such as precipitation. In this way one can estimate past precipitation amounts at a point, along a zonal transect or over a region. An example of more complex variables that can be reconstructed is stream runoff. It is often found to be positively correlated to precipitation, but negatively related to temperature because warmer than usual conditions increase evapotranspiration losses within the drainage basin. High temperatures can also limit growth processes in drought sensitive trees as well as through depletion of soil moisture.

Past records of two variables can also be inferred at a single point, yielding information of value for synoptic scale diagnostic analysis. The author illustrated this by comparison of very long records from bristlecone pine in the White Mountains of California. In their lower altitudinal range, ring width is limited by drought conditions,

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LaMarche, V.C., Jr. 1978. Continued

especially low precipitation, whereas at upper treeline growth is mainly limited by low temperatures. This diversity in climatic response allows a fuller characterization of past climatic variations in the area.

Although ring growth in trees can sometimes be approximated as a function of a single dominant climatic variable, a complex response to several environmental variables that are linked to climate is a more general case. Furthermore, the response to each variable, such as temperature, may change in magnitude or sign depending on the season of the year. For example, higher than usual temperatures in the previous autumn may be related to formation of a wider than usual ring in the current growing season, whereas high temperatures in the period immediately before and concurrent with the growing season may favour formation of a relatively narrow ring. Such relationships are readily interpretable in terms of the biological processes governing ring growth.

Recent work has evaluated the unusually cold winters of 1976-77 and 1977-78 in the eastern United States in the perspective of several hundred years of proxy climatic records provided by tree rings. These findings strongly indicate that severe winters similar to these have occurred with great frequency at certain times in the relatively recent past. During part of Europe's historic Little Ice Age, the period 1615 to 1655, 70% of the winters seem to have been characterized by circulation patterns and associated temperatures over North America similar to the winters of 1976-77 and 1977-78.

1. LAMB, H.H.

2. 1964

3. Trees and climatic history in Scotland.

4. Quarterly Journal of the Royal Meteorological Society 90:382-394

5. a. Scotland

   b. Nil

   c. Climatic change (proxy data)

6. This paper assesses evidence concerning the climatic history of Scotland in medieval and post-medieval times. Historical documents yielded the most valuable information for this study. Scotland probably shared the general experience of other northern lands of a warm epoch from 1070 A.D. or earlier to around 1300 A.D. The evidence from Scotland of frequent bad seasons and deteriorating condition of the land was almost entirely indirect and in itself inconclusive. Only after 1550 were enough facts known to make the latter stages of an economic decline, which culminated in the dire years of the 1690's, reasonably clear.

The period of economic decline from 1550 onwards was accompanied by a lowering of the prevailing summer and winter temperatures in Europe, abnormal frequency of northerly and easterly winds in the winters, and probably by an increase in storminess as well as wetness during summers in the latitude of Scotland. Evidence of prevailing winds and weather compiled by the author indicated that frequent depression tracks passed over or near Scotland between about 56 and 62° N in 80% to 85% of the summers between 1586 and 1640, and between 1688 and 1700. There are accounts from the 1600's, near the northwest coast of Scotland, of woodlands dying, being blown over after standing dead for several decades, then soon overgrown by moss and absorbed into the peat.

The present generalized vegetational zonation in the highlands of Scotland involves, with increasing altitude, a sequence from trees to tall shrubs to low shrubs and finally grasses and crypotogams. These altitudinal zones dip towards the northwest, due to increasing cloudiness, humidity, wind exposure, and lack of summer warmth. Severity of exposure to wind and lack of summe warmth are the main factors limiting plant growth in the Highlands.

1. LAMB, H.H.

2. 1966

3. On the nature of certain climatic epochs which differed from the modern (1900-39) normal.

4. IN: H.H. Lamb. The changing climate: selected papers. Methune and Co. Ltd., London. p. 59-113

5. a. Northern Hemisphere

   b. Nil

   c. Climatic change (hypotheses)

6. This paper is a survey of four climatic epochs since the ice age with an outline of the world climatic patterns prevailing during those epochs. The four epochs surveyed were: a) the post-glacial climatic optimum a warm period culminating between about 5000 and 3000 B.C.; b) the colder climatic epoch of the early Iron Age, culminating between about 900 and 450 B.C; c) the secondary climatic optimum in the early Middle Ages, around A.D. 1000 to 1200; and d) the Little Ice Age, a cold climate between about A.D. 1430 and 1850.

In the first of these four epochs, climatic zones were displaced towards higher latitudes; in the second, climatic zones were displaced towards low latitudes. In the third epoch, climatic zones were also displaced towards higher latitudes but to a lesser degree than in the first epoch. The fourth epoch appears to present a different pattern in the northern hemisphere, with an equatorward shift of climatic zones followed by return movements during the nineteenth century.

The amplitude of temperature fluctuations appears to have been greatest at high latitudes, so that the meridional gradient of surface temperature, at least between 50° and 70° N, must have been materially less in the warm epochs than in the cold ones. It appears, however, that temperatures on mountains, even in low latitudes, were raised 2 to 3° C in the warm epochs and lowered by 1 to 2° C below present values during the Little Ice Age. This means that the possibility remains that the meridional gradient of upper air temperature was actually less during the cold epochs, the surface temperatures in high latitudes being particularly unrepresentative at such times because of frequent strong inversions.

The following paragraphs summarize the author's tentative conclusions.

Climates of the four different epochs are amenable to interpretation largely in terms of a) intensity changes and b) latitude shifts of the main limbs of zonal circulation, accompanied by appropriate changes of

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wave length and trough positions in the belt of westerlies. The latitude and longitude changes must have had direct consequences in modifying climates in every latitude zone and have perhaps been more conspicuous than the changes of circulation strength.

There is some evidence that both the circulation in general and radiation available were weakened during the Little Ice Age by a few percent in the Northern Hemisphere and perhaps by up to 2% over the world, most probably due to volcanic dust. Correspondingly, it might be reasonable to suppose that circulation in general, and possibly the radiation available, were slightly above their twentieth-century strength in the early Middle Ages, particularly 1000 to 1200, though it would be safer to assume that they were not far different from modern values. Possibly the chief difference between the modern situation and that of the early Middle Ages warm epoch and of the major post-glacial climatic optimum around 5999-3000 B.C. lies in the duration of these warm epochs and the sea temperatures consequently attained in the Atlantic and Arctic.

As the energy of circulation increased, at least between 1800 and recent decades, the Northern Hemisphere circulation seems in general to have shifted poleward, perhaps mainly controlled by displacement of the main thermal gradient that accompanied the shrinking Arctic ice and winter snow cover on land.

It is clear that the extended arctic ice and cold water of the period around A.D. 1800 and earlier modified the Atlantic sector circulation, causing peculiarly great latitude shifts there and even local strengthening of the circulation and thermal gradients near the southern extremities of the extended cold troughs - in an epoch when over wider regions the energy was reduced.

Correspondingly, in the early Middle Ages warm epoch, when the energy generally available may be supposed to have been greater, if only because of higher sea temperatures, the circulation seems to have been not always stronger than now, and possibly sometimes weaker, in northern Europe. The likeliest reason for this seems to be the remoteness at that time of the Arctic ice limit.

When the general atmospheric circulation increases in energy the strongest effects should be expected in those sectors where a broad quasi-permanent ice or cold-water surface has protruded farthest toward low latitudes. At times, very strong circulations and very abnormal patterns might then be produced and become variable from year to year if the protrusion of Arctic ice were to break up or shrink rapidly. The peculiar climate course of the 1830's in the North Atlantic and neighbouring regions should probably be viewed in this light. That decade was one of extreme variations between persistent blocking and

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intense zonal circulations, most strongly developed in unusually high latitudes so that the low values of some of the intensity indices in that decade may be misleading.

Other researchers have pointed out that any long-period changes in the insolation available should produce a much quicker response over the great land masses than in the oceans and regions of quasi-permanent ice. This seems to be supported by the author's study of the state of the general circulation around 1800, when a trend towards increasing energy may have been already under way for about a century, with a peculiarly great equatorward displacement of the circulation over the North Atlantic Ocean.

Clearly, general trends of circulation strength must be judged by measures of the circulation in many different parts of the world and allowance made for passing phases in which misleading effects arise in regions affected by persistent ice or cold water, especially the North Atlantic.

To judge the position of the most recent decades in relation to longer term trends, it may be necessary to consider whether the appearance of rhythmic changes of wave position, wave length and circulation intensity affecting Europe represent some long period oscillation. So far the evidence seems against this, since the fluctuation was probably asymmetric in time, with the decrease spread over 300 to 500 years and the recovery nearly complete in 150 to 200 years. Nevertheless, there is evidence that the general circulation has for the time being fallen away from its maximum intensity between 1900 and 1930, evidently not due to volcanic dust. The trend of the North Atlantic circulation towards lower latitudes in winter requires further study.

1. **LAMB, H.H.**

2. 1969

3. Climatic fluctuations.

4. IN: H. Flohn, Editor, General Climatology, 2. World Survey of Climatology Volume 2. Elsevier Publishing Company, New York. p. 173-249

5. a. Northern hemisphere

   b. Nil

   c. Climate (air masses), Climatic change (hypotheses, proxy data)

6. The most promising avenue of investigation of climatic change is likely to be through study of changes in the general circulation of the atmosphere and oceans. Circulation studies provide a unified, synoptic view of the miscellaneous climatic variations noticed in different parts of the world.

At least the following different climatic epochs have left their mark in most parts of the world, and seem likely to repay further study by meteorologists.

1. The Climatic Optimum - the warmest epoch of Postglacial time, culminated between about 5000 and 3000 B.C.

2. The return to colder climates in the early Iron Age - a phase of markedly colder and stormier climate, probably culminated between about 900 and 450 B.C.

3. The Secondary (or "Little") Optimum in the early Middle Ages - a briefer, warm and relatively storm-free epoch, culminated between about 1000 and 1200 A.D.

4. The Little Ice Age - a time of marked cold climate, particularly in the northern hemisphere, between about 1430 and 1850 A.D.

During the Little Ice Age most parts of the northern hemisphere showed evidence of a colder climate than now. The arctic pack ice underwent a great expansion, especially affecting Greenland and Iceland; the inland ice also gradually advanced over former farmland in both countries. In Europe, prevailing temperatures in summer (June-August) were probably not much below modern levels, except between 1550 and the 1690's and principally in the northwest, north and east of Europe. The evidence points to prominent polar anticyclones and a southward displacement of the prevailing depression tracks in the northern hemisphere during the Little Ice Age. Annual mean temperatures were probably about 1° C below 20th century values over most of the world in the coldest phase of the Little Ice Age; ocean temperatures were probably lowest between about 1600 and 1800.

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Atmospheric conditions during summers of the coldest epoch of the Little Ice Age are thought to have been as follows. The strength of circulation was little, if any, weaker than now. The average position of the main westerly windstream was 5° or so south of the 1900-1939 normal; the main depression tracks were at 57° to 60° N over the eastern Atlantic, at times rather south of 57°, but reaching 60° N over Russia. There should also have been a change in the prevailing wave number, five to six waves having been normal around the hemisphere compared with four to five in the 20th century.

Climatic variations must depend on either: 1) changes in the net energy supply from outside the earth; or 2) changes in the amount of heat stored in the atmosphere and oceans or in the distribution of that heat. The author summarized information concerning possible causes of climatic variation as follows. It is reasonably certain that energy output of the sun cannot remain strictly constant over long periods of years, but no significant variations have so far been satisfactorily demonstrated, nor is it known what sort of period length is likely for a complete cycle. Variation during the course of the 11 or 22 yr sunspot cycle appears to be limited to a minute percentage in the ultraviolet. Variations of other astronomical factors affecting solar distance include: 1) varying ellipticity of the earth's orbit; 2) varying tilt of the earth's rotational axis relative to the plane of its orbit; or 3) changes in the season of the year in which the sun is nearest. These constitute oscillations with period lengths of 92,000, 40,000 and 21,000 yr respectively. Variations of transmission and absorption of solar radiation on passage through the atmosphere include the effects of volcanic dust or from nuclear explosions, the finer particles of which may remain suspended as veils in the stratosphere for 2 to 10 yr. Carbon dioxide, rapidly increasing in the atmosphere since 1850, water vapour and cloudiness all affect the heat budget of the atmosphere by direct absorption of solar radiation, by trapping long-wave radiation emitted from the earth and by re-radiating some of the latter back towards the earth.

Variations of the albedo of the surface and the atmosphere are themselves produced by year-to-year climatic changes, but they affect the energy supply available chiefly because of the reflection of radiation from high-albedo surfaces such as snow, ice and the upper surfaces of clouds. The albedo of the surface is also changed by the activities of man, particularly in forest clearance.

Variations in the amount of heat stored in the oceans are likely to occur through changes of evaporation due to changes in the atmospheric circulation as well as to any changes in the direct penetration of solar energy to the water surface.

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The wind-driven ocean circulation redistributes the heat content of the oceans to different latitudes and different depths. Long-period cyclical changes could arise through upwelling of water masses with an excess or deficit of heat acquired decades or centuries earlier. It is unlikely, however, that such periodic changes could ever constitute more than a minor effect superimposed upon the climatic trend proceeding at the given time.

Changes in the extent of polar ice result from variations in the atmospheric circulation and probably also from changes in the radiation receipt at the surface. But they also influence climatic changes by altering the albedo, heat conductivity of the surface, roughness of the surface and the amount of evaporation.

If indeed, the major temperature variation of the last 800 yr represents a single long-period variation either of solar output or of absorption of solar energy in layers of the earth's atmosphere high above the surface, one must still suppose the occurrence of some superimposed events, probably of terrestrial origin, that made this particular oscillation attain a higher "maximum" in 1000-1200 A.D. and lower "minimum" in 1550-1700 than any for long before. In the case of the Little Ice Age, it seems likely that the exceptional volcanic activity between about 1550 and 1831 maintained frequent dust veils in the stratosphere and so contributed to the loss of incoming energy as far as the lower atmosphere was concerned.

The effectiveness of carbon dioxide as a factor of climatic change is much more doubtful than that of volcanic dust. The case has been argued that the increasing CO_2 content of the atmosphere explains the global climatic warming since 1850. Estimates of the theoretical magnitude of the CO_2 effect however differ widely, and there are many other uncertainties. The CO_2 theory fails to account for the long climatic decline between 1300 and 1600, for the early stages of the warming after 1700 and for the rather sharp decline after 1950.

In conclusion, the most defensible information so far has come from atmospheric circulation studies. The world-wide phenomenon of increasing, and then lately decreasing strengths of the main arms of the mean circulation has been described by the author. The ocean currents have varied in sympathy, and sea ice has receded and expanded in response, though with some lag. A new downward tendency of the indices of the zonal circulation from about 1930 onwards was the earliest sign of a halt or reversal of the previous long warming trend. For the present, therefore, a continuing watch upon the main arms of the general circulation is the best approach for an early warning of the onset and progress of climatic changes.

1. LAMB, H.H.

2. 1977

3. Climate: present, past and future. Volume 2. Climatic history and the future.

4. Barnes and Noble Books, New York. 835 p.

5. a. Northern hemisphere

   b. Mil

   c. Climate (air masses, temperature, insolation), Climatic change (hypotheses, proxy data), Climatic variation (regional, temporal, temperature, precipitation)

6. In regard to the apparent association between the mean July position of the arctic front and the northern treeline in North America (Bryson 1966) and in Eurasia (Krebs and Barry 1970), the author suggested that the relationship of the air mass boundary and vegetation boundary is probably a two-way relationship, with the vegetation distribution a natural response to the temperature and radiation conditions associated with the air masses on either side of the Arctic front but the differences of surface roughness, albedo and moisture helping to maintain the general position of the front. It is reasonable to take the shifts of the vegetation limits under other climatic regimes in the past as indicating the positions of the airstream boundaries which prevailed in the times concerned.

The changes in circulation regime observed since the decade from 1940 to 1950 have brought a lowering of the overall temperature to about the level of 1900 to 1920. This cooling has probably been longer sustained than any other period of downward trend since the examples known in England of the decades 1660 to 1690 and 1730 to 1770. Because of the almost unbroken warming long-term trend of world climate since instrument measurements began there is an obvious need to extend the climatic record further back by various forms of proxy data.

Periodogram and spectral analyses of the series of monthly mean temperature values in England over the last 290 yr suggest quasiperiodicities of 20 to 25 yr and about 45 to 55 yr play a modest but significant part in the variations in at least several months of the year. Periods of these lengths were also found to be among the most prominent in tree-ring series in pines near the Norwegian coast at 68° N and are suggested by long records of the fisheries and sea temperatures.

There is some coherence between long-term temperature trends in Japan and in other locations of the northern hemisphere. There is evidence that some disturbance affecting the prevailing winter temperature makes steady progress westward around the hemisphere so as to complete one circuit in

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about 600 yr. This phenomenon, however, accounts for less than half of the variance of winter temperatures and its range differs in different regions. An important component of the remaining variance must be the world wide fluctuation of temperature which produced the warmth of the early Middle Ages and the cold of the Little Ice Age about five centuries later.

Not only changes of the mean temperature level but also changes of the year to year variability is important. The variance of summer temperatures in Sweden in the past 200 yr has tended to be greatest in periods of meridional circulation. Similarly, variance of the winter temperatures in western Europe tends to be greatest in periods when westerly winds are least prevalent.

Another noteworthy aspect of the temperature changes observed is the decrease, at all seasons of the year, of the south to north temperature gradient across middle latitudes which accompanied the secular warming of climates. This is an obvious consequence of the fact that the warming was strongest in high northern latitudes. It might also be an expected result of the increasing vigor of the general atmospheric circulation and its heat transport. The question is then raised regarding how that increase of energy of the atmospheric circulation was supplied. In particular, it seems from observation of the reverse changes since 1950 that the middle and upper troposphere over subtropical latitudes was more intensely warmed by subsidence in the anticyclones there during the warm epoch of the early twentieth century, while the temperatures prevailing in those layers of the atmosphere over the Arctic and high latitudes generally were not much changed. Hence, in those layers the south-north temperature difference may actually have increased with the secular warming that took place up to 1950. Two other factors must be mentioned to explain the decline of the latitude gradient of surface temperature in middle latitudes during the warming epoch: increasing vigor of the wind circulation is very destructive of surface temperature inversions and hence to the development of very low temperatures over ice and snow surfaces in the northern regions; with the secular warming, the mainstream of the wind circulation was tending to be displaced northwards, snow and ice cover on land and sea was becoming less frequent near the northern United States, and hence the locus of strongest temperature gradient moved generally north.

Air temperatures prevailing over most of the globe reached their maximum about the early 1940's, towards the end of the decades of strongest atmospheric circulation, and their subsequent fall to the level maintained from 1965 to 1976, or after, seems likely to be the longest continued downward trend since 1700. Maps show that the cooling at the surface in the 1960's was greatest in just the places where the warming in the early decades of this century had been greatest and was of about the same magnitude. Overall average mean sea level pressure values

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indicate an increased flow of air right across the Arctic towards the Norwegian Sea, which must have caused an increased wind drift of the water northward through the Bering Strait and of the Arctic pack ice towards the East Greenland exit.

In 1970-71 an abrupt change took place in the northern hemisphere which produced an unbroken run of five very mild winters in Europe and some southern and eastern parts of the U.S.A. and the Far East while most of the rest of the hemisphere - particularly in the Arctic and low latitudes over the oceans - had a predominance of cold winters. The coldness of the other seasons of the year (also in Europe) meant that the overall average temperature for the year over the northern hemisphere continued at the level of the 1960's, about 0.2° C below the 1930 to 1960 average. The explanation of this change seems to lie in the fact that in 1970-71 the Canadian sector of the Arctic became for the first time fully involved in the Arctic cooling and quickly became so cold that the thermal gradient between the subtropical Atlantic with the Gulf Stream water and Arctic Canada was greatly strengthened. This revived the intensity of the atmospheric circulation over the Atlantic sector, particularly in winter, deepening the Iceland low, producing frequent southerly and southwesterly winds over Europe and in the Norwegian Sea and causing the ice to recede once more in the Iceland and Barents Sea sectors. The warmth does not seem, however, to have penetrated the inner Arctic to the same extent as in the early twentieth century warming, and it is not clear that the shift of the cold centre of the northern hemisphere circulation to the Canadian and Pacific side in the early 1970's is in itself a mechanism capable of bringing about a renewal of the general warming of the Arctic and of the hemisphere. At the same time frequent cold northwesterly winds intensified the Labrador Current and brought more ice into the western and northwestern Atlantic. Some places in Newfoundland and in the interior of Canada farther north experienced in these years the lowest temperatures ever recorded there. The net effect was that the area of snow and ice surface integrated over the year over the northern hemisphere, which had increased 3% since the satellite surveys of it first became possible in 1967, underwent a sharp further increase in 1971. In 1972 and 1973 it was 12% more than in 1967 and, despite a decreasing trend in 1973-74, steadied in 1974 at 11% above the 1967 extent. Probably because of the intensification of the winter circulation, the increase in these years has been mainly in a lengthening of the snow season in spring and autumn and not any greater area of snow in mid-winter.

Since blocking anticyclones tend to dominate somewhat different longitudes from one year to the next, and sometimes from one spell to the next, climatic periods with frequent blocking in middle latitudes tend to show an enhanced year-to-year variability. With the anticyclone in one position a given country may experience a long spell of warm southerly winds or of drought, while another sector in the same altitude zone has

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prolonged cold northerly winds or wet weather; and in the following year or a few years later, the same country may have the opposite experience.

Periods of frequent blocking are similarly associated with an enhanced liability to both hot and cold spells and with temperature extremes. The incidence of extreme months with either great heat waves or persistent freezing temperatures in England has varied since A.D. 1660. The 30-yr totals of months with mean temperatures above 17.5° C and below 0.5° C, added together, are highly significantly negatively correlated with the frequency of southwesterly surface winds. In other words, both extremes occurred more notably during periods of frequent blocking of the westerlies. Such times could be said to have a more continental character. Only in the late 1600's and around 1810 to 1840 and in the 1880's was the frequency of the cold extremes high while months of extreme warmth remained rare. The reverse situation, with extreme warm months relatively frequent and extreme cold months rare, prevailed mainly between about 1900 and the 1930's, except for the brief instance between 1710 and 1730.

The most basic aspect of climatic changes is probably to be found in relatively small amplitude changes in the energy absorbed and the temperatures prevailing in the oceans in low latitudes, but because these affect the energy and scale of the atmospheric and ocean circulation they result in much bigger changes in high latitudes. This means that the changes are most easily determined in high latitudes. The amplification at high latitudes is, however, important in its own right because of the changes in the extent of ice and snow and, hence, albedo and the total heat intake. These variables, in turn, influence the location of the strongest thermal gradients, and so the jetstream, and the development and steering of cyclones and anticyclones with their heat transport, ultimately producing large amplitude changes in the ranges of the main ocean currents.

Japanese researchers have demonstrated that the surface temperature anomalies in the northern hemisphere following volcanic eruptions in the years 1952 to 1970, regardless of where the eruption occurred, were in all cases greater in high latitudes between 50° and 90° than they were below 50° N.

Some investigators have been able to simulate most of the supposed course of global mean surface air temperature over the past 370 yr by use of a formula expressing variations of the solar energy available in terms of sunspot numbers. Because of this, the author suggests that high priority should be given to obtaining high precision extra-terrestrial measurements of variations of solar beam intensity.

1. LAMB, H.H.

2. 1978

3. Towards an understanding of climatic change: its impact in history and in the modern world.

4. IN: K. Frydendahl, Editor, Proceedings of the Symposium on Climatic Changes and Related Problems. Danish Meteorological Institute, Copenhagen, Climatological Paper No. 4. p. 181-187

5. a. Northern hemisphere

   b. Nil

   c. Climate (air masses), Climatic change (hypotheses, proxy data), Climatic variation (temporal)

6. Included in this paper is a discussion of the timing and rapidity of climatic changes. Studies of the longest ocean-bed sediment cores seem to have established that cyclical variations of the earth's orbital characteristics, on time scales of about 100,000, 40,000 and 20,000 yr, are the main control of the timing of ice age and interglacial variations. Although the ability to determine exact dates of the main temperature changes is blurred by lags in responses of the biotic wo d, and by the thousands of years required for ice sheets to melt, it is clear that some of the climatic changes that were critical for the biosphere and for existence of ice sheets took place much more quickly than the effect of orbital changes on the radiation budget would indicate.

Some of these relatively rapid climatic changes may be due to cyclical changes of solar output, variations of tidal force, or variations of volcanic activity and dust in the atmosphere. The author gives several examples of climatic analyses that show strong traces of periodicities on time scales, which if superimposed on the orbital variations, could produce rapid changes of climate. The examples are as follows: 1) an approximately 2,000 yr fluctuation in the estimated glacial and postglacial temperatures in England; 2) a 2,000 yr period has been noted in glacier variations, although in some parts of Europe and North America a 1,000 yr oscillation seems prominent in glacier variations and roxy temperature data; 3) an oscillation of close to 200 yr in the derived temperatures of central England since the early Middle Ages and in the frequency of southwesterly winds in England over about the same period; 4) fluctuations of close to 50 yr length in pressure gradients of northerly and southerly winds and in the frequency of cyclonic centres over the British Isles - North Sea region; 5) other indices of blocking/mobility of weather systems over the northeast Atlantic - European regions show both 50 yr and approximately 30 yr periodicities.

Continued ...

The author's analyses suggests that the greatest extremes, which must require stationary weather situations, have tended to signal some long-lasting change of climatic regime. This observation suggests that the changes of wind circulation regime that bring about changes of climate may be almost instantaneous, as in the case of the increase of blocking and decline of the zonal index of the westerly winds about 1940, even though the sea temperatures and ice, and hence the surface air temperature regime, may take some years or even decades to become fully adjusted to the change. The response of glaciers is likely to be even longer delayed, particularly in the case of a changeover from retreat to advance. Major glacial advances may take the form of just a few quick surges after many years of slow build-up of the ice supply in the source area. Adjustment of the vegetation in central North America to the major postglacial climatic changes seems to have been achieved within about 45 yr in the case of drought killing oak forest, but took from 140 to 200 yr where it was a question of new species of forest trees moving in and displacing the former forest. In Europe, where the ice-age refugia of the main forest trees were beyond the Alps, several thousand years were required before development of a climax forest fully adapted to the postglacial climate.

The author concluded that it is the suddenness of the changes of wind circulation regime, particularly when blocking brings a long spell of weather which produces some extreme season of drought or raininess, or high or low temperatures, that brings the greatest impacts on the biosphere and on the affairs of man. The extremes that arise with long spells of blocking, particularly if superimposed on some trend which has changed the surface conditions of the earth, may go beyond all the experience and preparations of people living at that time. Furthermore, our present economy is extremely vulnerable to climatic fluctuations. The author stated that we appear to be in one of those periods of frequent blocking of the westerlies, when the year to year variations increase and which could signal some more lasting changes. There is therefore an urgent need for more climatic research to achieve a better understanding and greater forecasting capacity.

1. LAMB H.H. and H.T. MÖRTH

2. 1978

3. Arctic ice, atmospheric circulation and world climate.

4. The Geographical Journal 144:1-22

5. a. Northern hemisphere

   b. Nil

   c. Climate (air masses, temperature), Climatic change (hypotheses, proxy data), Climatic variation (regional, temporal)

6. After a brief outline of the known history of arctic ice and its interactions with the general wind circulation, an account is given of the transport and redistribution of heat over the earth which largely determines the arctic climate and the patterns of climate prevailing at any given time over the rest of the globe.

This study draws attention to climatic differences that may arise over periods from a few weeks to some years, due to changes of prevailing wave length and wave position in the flow of the upper westerlies (circumpolar vortex). These differences are likely to be particularly strong in periods when large amplitude waves and blocking are common, for example since about 1955 to the present and also in the 1940's. The long spells of anticyclonic or cyclonic weather which then prevail are liable to produce a great diversity of extremes of both temperature and rainfall in the middle latitudes of either hemisphere. Year to year, and possibly even decade to decade, variability seems to go with periods of blocking. This variability affects rainfall as well as temperature and may be one of the aspects of climatic change that has the most serious agricultural and economic consequences.

The authors also draw attention to some differences in climate that characterize different latitudes. In the climatic variations of the past three centuries, all the climatic zones and the accompanying bands of wind circulation have tended to move north or south together, with important responses in the ocean circulation. The climatic indicators that the authors examined confirmed that, although the cooling trend which set in around 1950 has levelled off in recent years, there is as yet no sign of a return to the warmer regime that dominated the first half of the century. The authors suggest that natural causes are still dominant in producing the climatic changes observed, but the effect of increasing atmospheric CO_2 as a result of human activities is probably already sufficient to be moderating what would otherwise have been a more severe global cooling of the natural climate since 1950.

1. LARSEN, James A.

2. 1966

3. Relationships of central Canadian boreal plant communities: studies in subarctic and arctic bioclimatology, II.

4. University of Wisconsin, Department of Meteorology, Madison, Wisconsin. Technical Report No. 26. 26 p

5. a. Canada, Minnesota, Wisconsin; Index maps (all in Keewatin, Manitoba, Ontario and Saskatchewan); B.32, B.27, B.22a, B.18a, B.15, B.14, B.8, B.4

   b. Black spruce, jack pine, aspen, white spruce, balsam fir

   c. Climate (air masses), Climate/growth (direct relationships, indirect influences), Climatic variation (regional)

6. The study objectives were to demonstrate that plant community variations over distance can be related to variations in a variety of environmental factors and that some proportion of this vegetational community variation is related to climatic variation. Other contributing factors to community variation include variations in soils, ecotypic variations in species, and perhaps such influences as geological history and post-glacial migration patterns of species.

The data employed were obtained principally from the understory floristic associations of black spruce stands, with some information from aspen, jack pine and mixed white spruce-balsam fir stands. Data were obtained from Ennadai Lake in the District of Keewatin, Waskesieu Lake in Saskatchewan, Brochet, Lynn Lake, Ilford, Rocky Lake, Clear Lake and West Hawk Lake in Manitoba, Raven Lake, Klotz Lake and Remi Lake in Ontario, Bemidji in Minnesota and Trout Lake in Wisconsin.

From climatic descriptions it is apparent that isopleths of such climatic parameters as mean temperature, temperature extremes, degree days, mixing ratios, precipitation, limit of permafrost, and dates of first and last frost generally follow a northwest to southeast orientation in this region. After statistical analyses of the study sites, the author concluded that a correspondence could be discerned in this region between climate and species composition of the vegetation communities under consideration.

The ordination of coefficient of similarity values indicated that the extreme southern tier of study areas had less in common with one another than did the northern areas with one another. Data from air mass analyses indicated that these regional vegetational differences could be related to climatic regimes that are as distinct as the vegetational communities are distinct and that the southern zone possesses greater climatic variability.

Continued ...

Larsen, J.A. 1966. Continued

Adaptations of plant species not only to climate but to substrata and other plants (as they influence moisture, nutrient and light conditions) are involved in competitive community relationships. So far, efforts have been made only to infer similarities of environment from similarities of plant communities. The relationship is multifactorial, and with present lack of knowledge of the effect of even relatively gross soil differences, little can be said concerning the relative importance of the various factors.

The author concluded that vegetational community structure can be rather definitely related to climatic parameters, and that the broad climatic patterns of the region possess discernable correlations with the vegetational communities found there, particularly the understory communities of the spruce forest which were studied most intensively. It would appear practicable to employ these species groups as natural indicators of the airmass frequency characteristics of the atmosphere in this region.

1. **LARSEN, James A.**

2. 1971

3. Vegetation of Fort Reliance, Northwest Territories.

4. The Canadian Field-Naturalist 85:147-178

5. a. Canada; Index map NP-12/13; District of Mackenzie; B.27, B.32

   b. Nil

   c. Climate/growth (latitude), Climate (air masses)

6. The majority of this article describes plant communities present in the region between the east arm of Great Slave Lake and Aylmer Lake in the Northwest Territories. The vegetation of the area shows a rapid and marked transition within 30 km of boreal forest, with strong southern boreal affinities around Fort Reliance to tundra-dominated landscape at the southern end of Artillery Lake.

There were indications that the arctic and boreal components of plant communities overlap to a greater extent near Fort Reliance than in the areas around Ennadai Lake to the east. It appeared that, unlike areas further east, in the vicinity of Fort Reliance there was also a correspondingly more abrupt transition between the dominant pacific and southern air masses to the south and the arctic air masses to the north. The author suggested that, for at least some of the species, climatic conditions near Fort Reliance permit an intrusion of boreal and arctic species. To the east, the ecotone between southern boreal, northern boreal and tundra is more gradual, so that such an overlap of arctic and southern boreal species is not found in the communities dominating the landscape. The presence of this obvious zonation can be interpreted as a consequence of a corresponding zonation in climate, and in view of the general monotony of the terrain throughout this vast region, the author suggests that this is the simplest and most generally satisfactory explanation. Additional evidence for this sharp climatic zonation was indicated by the spring breakup of lakes which differed by two weeks over a distance of 150 km.

1. **LARSEN, James A.**

2. 1971

3. Vegetational relationships with air mass frequencies: boreal forest and tundra.

4. Arctic 24:177-194

5. a. Minnesota, Wisconsin, Canada; Index maps (all in Northwest Territories, Saskatchewan, Manitoba, Ontario); all boreal forest regions in Northwest Territories, Saskatchewan, Manitoba, Ontario

   b. Aspen, Black spruce, Jack pine, White spruce

   c. Climate (air masses)

6. This paper reports an analysis of the relative abundances of certain species in several kinds of plant communities found in central and northern North America. The species frequency values show correlations with air mass frequencies that are sufficiently high to warrant the conclusion that distribution and frequency in plant communities are a response to climatic conditions.

The four forest communities sampled were: black spruce forest; white spruce and/or balsam fir forest; jack pine forest; and aspen forest. Rock field tundra, tussock muskeg tundra and low meadow tundra communities were also sampled in this analysis of shrub and herbaceous species in relation to frequencies of given air mass types. The four types of air masses analyzed in relation to plant species frequencies were: arctic air; Pacific air; Alaska-Yukon air; and southern air.

Some examples of herb and shrub species that show relatively high correlations to specific air mass types are listed below for the black spruce and jack pine community types.

A. Black spruce community:

1. Species with high correlation with arctic air masses
   Empetrum nigrum
   Rubus chamaemorus
   Vaccinium uliginosum
   Vaccinium vitis-idaea

2. Species with high correlation with Alaska air masses
   Andromeda polifolia
   Picea mariana seedlings

3. Species with high correlation with southern air masses
   Cornus stolonifera
   Galium triflorum

4. Species with high correlation with Pacific air masses
   Galium triflorum
   Rubus pubescens

Continued ...

B. Jack pine community:

1. Species with high correlation with Alaska and arctic air masses
   Vaccinium vitis-idaea

2. Species with high correlation with Pacific air masses
   Maianthemum canadense

3. Species with high correlation with southern air masses
   Alnus rugosa
   Aster ciliolatus
   Cornus canadensis
   Diervilla lonicera
   Gaultheria procumbens
   Lycopodium obscurum
   Maianthemum canadense
   Oryzopsis asperifolia
   Trientalis borealis

All species in the black spruce community that possess high positive correlations with arctic air also show high correlations with that same air mass type as part of the white spruce community. Species in the aspen community show little correlation with either arctic or pacific air, but a significant group is positively correlated with Alaska-Yukon air and negatively with southern air. There are few species in the jack pine community that are positively correlated with arctic or Alaska-Yukon air but nine species are correlated positively with southern and pacific air.

Species that are correlated positively with arctic air are also correlated positively with Alaska-Yukon air and species correlated with pacific air are often also correlated with southern air. This suggests that the plant species are not responding directly to a specific air mass type but rather to a northern or a southern climatic component. The author stressed that the climatology of a region cannot be described as simply a combination of the air mass frequencies, since there are other factors to be considered, among them such influences as the direction of resultant winds (Bryson 1966), wave structure of frontal zones, and gradual air mass modification during movement from region to region; air mass frequency is but one of the measurable parameters indicative of the prevailing climatic regime in a given area.

Only in the black spruce and white spruce forest communities and the rock field tundra community do those species with high air mass correlations attain a consistently dominant position in the sampled stands of these communities. As a result, these communities are of the greatest indicator value for correlations between vegetation and climate in these regions.

It is of ecological significance that northward there are communities in which at least some species may be found to be correlated with

Continued ...

Larsen, J.A. 1971. Continued

macroclimatic parameters. The greatest difficulty in correlating environmental factors with vegetational structure would be encountered in communities of lower slopes, meadows, shorelines and marshes, because physical characteristics of abundant water tend to override other environmental influences.

The author noted seven species that correlate with different air mass types in different communities. These are ubiquitous species that range widely through forest and tundra. They increase in frequency northward through the forest and then decrease northward beyond the forest border in the tundra communities. In the former case they correlate positively with arctic air and in the tundra communities they correlate positively with pacific air. The species of this group, including **Empetrum nigrum, Ledum decumbens, Rubus chamaemorus** and **Vaccinium uliginosum**, attain highest frequencies in the communities of the forest-tundra ecotone where they are dominants.

1. **LARSEN, James, A.**

2. 1972

3. Growth of spruce at Dubawnt Lake, Northwest Territories.

4. Arctic 25:59

5. a. Canada; Index map NP-13/14; Keewatin; B.32

   b. Black spruce

   c. Treeline studies (growth, climate)

6. The author stressed that the concept of treeline is confusing since a lone tree far beyond the forest border must be included within the "treed" zone. Dwarfed and decumbent black spruce exist over a wide zone north of the forest border in Keewatin and Eastern Mackenzie. While reproduction is primarily by layering, seedlings are consistently seen in areas around Dubawnt, Ennadai and Yathkyed lakes. Seedling mortality in all species in these areas is high, but species survival is most markedly conditioned by the frequency with which very severe seasons occur (for example, a series of very cold summers). Seedlings that survive a series of favourable years can then live and grow through a fairly long series of rather severe years.

The author has observed anomalously successful young trees on exposed sites around Ennadai Lake. He does not take these to indicate a major climatic amelioration but as evidence of a few favourable years. There is a grove of spruce with stem diameters up to 20 cm at Yathkyed Lake (62 53 N, 98 52 W) which would put the treeline far out into the barrens. It is concluded that the northward extent of the range of spruce, anywhere within which will be found the occasional "tree" on favoured sites, is the result of some sequence of events permitting the individual to grow but this is not necessarily a result of a general change in climatic conditions. A much better indication of climatic change would be a shift in the position of the forest border, arbritarily defined as the area where the terrain is 50% covered by forest and 50% covered by tundra.

1. **LARSEN, James A.**

2. 1974

3. Ecology of the northern continental forest border.

4. IN: Jack D. Ives and Roger G. Barry, Editors, Arctic and alpine environments. Methuen and Company Ltd., London. p. 341-369

5. a. Alaska, Minnesota, Wisconsin, Canada; Index maps NR-7/8/9, NR-9/10/11/12, NQ-7/8/9, NQ-9/10/11/12, NQ-12/13/14, NP-11/12, NP-12/13, NP-13/14, NO-13, NO-14, NO-15, NO-16, NO-18, NO-19, NO-20, NN-15, NN-16, NN-17, NN-18, NN-19, NN-20, NN-21; District of Mackenzie, District of Keewatin, Saskatchewan, Manitoba, Ontario, Quebec, Newfoundland; B.32, B.27, B.13a, B.13b, B.5

   b. Black spruce

   c. Climate (air masses, precipitation, temperature, insolation), Climate/growth (latitude), Treeline studies (growth, climate)

6. This review provides a comprehensive summary of the climatology of the forest-tundra ecotone in North America. The paragraphs below summarize the author's review without c' ing the large number of original authors whose work provided background information.

The position of the forest border in northern Canada has long been regarded as a convenient, and perhaps the most significant, boundary for separating the faunal, vegetational, climatic and ethnic characteristics of arctic and subarctic regions. A variety of climatic parameters have been considered significant in determining vegetation zones in Canada. The fairly definite correspondence between the 10° C isotherm for the warmest month and the northern limit of trees has been amended by more recent research to consider the mean temperature of the coldest months as well as the warmest.

Classification of climates by means of a relationship computed between water supply and estimated evapotranspiration has been employed to delineate climatic regions of Canada. Boundaries between forest zonal divisions tend to follow isopleths of po' tial evapotranspiration but are independent of moisture gradients. For example, a correspondence between forest divisions and potential evapotranspiration in Labrador-Ungava has been recorded, as outlined in Table 1. Potential evapotranspiration is a direct function of temperature.

Continued ...

TABLE 1. Forest divisions and potential evapotranspiration (PE) in Labrador-Ungava (Hare 1950).

Division	Typical value of PE (cm) along boundaries	Dominant vegetation
Tundra		Tundra
	30-32	
Forest-tundra ecotone		Tundra & lichen woodland intermingled
	36-37	
Open boreal woodland		Lichen woodland
	42-43	
Main boreal forest		Closed forest with spruce-fir associations
	47-48	
Boreal-mixed forest ecotone		Closed forest with white & red pine, yellow birch & other non-arboreal invaders
Great Lakes & St. Lawrence mixed forest	50-51	Mixed forest

Wide variations in moisture occur within vegetational divisions without any readily apparent effect upon vegetational characteristics. There is evidence that thermal efficiency rather than moisture governs the distribution of northern forest types in the regions considered. The isopleth of 10° C accumulated month-degrees above the 6° C threshold, for example, shows a close correspondence to the northern forest border. There is the possibility that biotic and climatic limits positioned at the forest border may be the consequence of atmospheric circulation patterns determined by overriding radiative controls, and hence both may be effects rather than one the cause and the other an effect.

In Alaska, there is a correspondence between vegetation types with the number of degree-days above 10° C and also with the mean temperature of the coldest month. The approximate southern limit of continuous permafrost coincides well with the northern limit of the forest-tundra ecotone in northwestern Canada, but in Eurasia the zone of continuous permafrost extends southward into the forested region.

From July through October, the forest border coincides with the average position of the climatic boundary between arctic air on the north and airmasses of pacific and continental origin on the south. Airmass frequency analyses and maps of resultant average wind directions demonstrated a close relationship between the position of the northern

Continued ...

forest border and the mean position of the arctic front in summer. This leads to the conclusion that the boreal forest in North America corresponds to the zone over which the mean position of the arctic front oscillates during the course of the average year. This correspondence is most apparent in Canada west of Hudson Bay, where the forest-tundra boundary is relatively sharp. This correlation may not be as applicable in Labrador-Ungava where the location of the climatological front is not as definitive. The latter circumstances may have an important bearing on the fact that there exists a somewhat broader forest-tundra ecotone in the Labrador-Ungava region than there is further northwest in the boreal region. In other boreal areas, frontal analysis of climate in northern Eurasia has indicated a strikingly close coincidence between the forest-tundra boundary and the median position of the arctic front, especially in the case of the montane areas of the eastern Soviet Union.

Global solar radiation per annum in Canada increases southwards from values near 90 kilolangleys at the arctic treeline to about 110 kilolangleys at the boundary between open woodland and closed forest zones. A more significant variable is absorbed solar radiation, which ranges from 50 to 55 kilolangleys at the forest-tundra treeline to about 80 kilolangleys in the northern forest proper.

Zonal divisions of vegetation appear to correlate closely with mean net radiation. With the forest strongly heated, and the tundra much less so, an intense air temperature gradient develops. The low albedo of dense forest permits more rapid warming of the forest in spring than is the case with tundra, and hence the above-freezing season is about 50 days longer in the forest than on nearby tundra, even though these zones are separated by less than 400 km. Structure of vegetation in this case markedly influences the physical climate, just as the latter provides the energy resource on which plant growth depends. Across Canada, zonal divisions of the boreal forest seem to be in close relation with the distribution of annual net radiative heating, and even more closely with warm season net radiative heating. The arctic treeline in Canada occurs near an annual net radiation of 18 to 19 kilolangleys.

Progressing southward, standing phytomass increases from less than 5 t/ha in arctic tundra to as high as 25 t/ha just north of the forest border; further southward in the boreal zone it reaches values as high as 300 to 400 t/ha. In relation to annual net radiation, much more phytomass exists per unit of energy absorbed in the southern boreal forest than in the southern tundra.

In a comparison of rates of growth on individuals in black spruce stands in Wisconsin, Manitoba and Ontario, the rates varied markedly from stand to stand with a general narrowing of the range of growth rates northward. At the northernmost study area of Ennadai Lake in the

Continued ...

Northwest Territories, the rate of growth on optimum sites does not much exceed the growth rate of the poorest sites, indicating that only the most narrow range of habitable environment is available at the northern edge of the forest. Analysis of growth rates of black spruce has led to the conclusion that the location of the theoretical black spruce treeline coincides closely with the present northern limit of spruce.

Shading by the tree canopy results in persistent ice lenses beneath spruce trees at the northern edge of the forest. Roots of trees and other plants in the shade are thus very often colder than roots of tundra plants that receive the same amount of insolation. This may be a significant factor in limiting tree growth at the northern forest border.

A comparison of the width of the forest-tundra transition at three locations, Ennadai Lake, Artillery Lake and near the Mackenzie Delta, revealed that the transition zone is narrowest, about 30 km, at Artillery Lake. There is a slight altitudinal gradient that possibly contributes to the abrupt transition from forest to tundra in the Artillery Lake area. It is noteworthy that at Artillery Lake, both boreal and tundra species are often found growing on adjacent or nearby sites. There are strong indications that the climatic gradient is steeper at Artillery Lake than in the Ennadai Lake region where southern boreal and tundra species are separated by a much wider ecotonal area even though the forest itself ends abruptly in the Ennadai Lake area. In the western Canadian Arctic, the forest border is much more irregular than in the Artillery Lake and Ennadai Lake areas, the consequence of somewhat greater differences in elevation and also perhaps of maritime influences that originate in the Arctic Ocean. In mountainous areas the ecotone is irregular and patchy due to the effects of slope, topography and montane climatic influences.

1. **LARSEN, James A.**

2. 1980

3. The boreal ecosystem.

4. Academic Press, New York. 500 p

5. a. Canada, Minnesota; Index maps (all in boreal zone); All boreal forest sections in Canada

   b. Black spruce

   c. Biomass (tree, shrub/herb, moss/lichen), Climate/growth (direct relationships, indirect influences, latitude)

6. This comprehensive text contains separate chapters on climate, nutrient cycling and productivity in boreal forests of North America, highlights of which are summarized below.

The author questioned the usefulness of air mass analyses in studies of relationships between climate and vegetation, and suggested that relationships between vegetation and temperature, humidity, precipitation and wind operate at mesoscale and microscale levels rather than the macroscale levels of air masses.

The structure of vegetation markedly influences the physical climate. Across Canada, zonal divisions and standing crop of the boreal forest seem to be in close relation to the distribution of both annual and warm season net radiative heating. The author cited data from Hare and Ritchie (1972) which indicated that standing phytomass increases from less than 5 t/ha in arctic tundra to as high as 25 t/ha just north of the forest border. It then rises rapidly southward in the forest to values as high as 300 to 400 t/ha. In relation to the annual net radiation, much more phytomass exists per unit of energy absorbed in the southern boreal forest than in the southern fringes of the tundra.

There is a remarkable variety of boreal plant communities on low, flat land surfaces. For example, in northwestern Minnesota, several million hectares of forested peatland occupy the bed of former glacial Lake Agassiz. Black spruce is the most abundant tree These Lake Agassiz peatlands possess significant surface slopes. Areas located downslope from mineral soil islands in the peatlands support a rich swamp forest which often contains tall black spruce, tamarack and northern white cedar, a shrub understory dominated by speckled alder, and an assemblage of mosses, herbs, grasses and sedges. These areas contrast sharply with adjacent stands of muskeg dominated by dwarf black spruce, **Sphagnum** mosses and ericaceous shrubs. There is circumstantial evidence that forests located downslope from islands are productive and floristically rich because these sites are fertilized by mineral-bearing groundwater. The adjacent muskegs are unproductive and floristically poor because they have been isolated from the mineral-bearing waters by the accumulation of **Sphagnum** peat.

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In the southern parts of the boreal forest, black spruce is found in a wide range of habitat types, with the consequence that growth rates vary markedly from stand to stand and range over a wide scale of values. A narrowing in average growth rates can be discerned along the latitudinal gradient northward. At the northern forest border, the rate of growth on optimum sites does not greatly exceed the rate on the poorest sites, indicating that only the most narrow range of habitats is available at the northern edge of the forest. The best available sites permit only the minimum growth consistent with continued survival; these sites have growth rates comparable to those shown by trees only on the poorest sites in regions to the south.

Investigations in Manitoba revealed that a sampled peatland had a total net primary production of 1,943 g/m^2 but in the treeless part of the peatland, subsurface biomass of stem materials was 4.6 times the value of the aerial biomass. With so much of the total biomass found below the peatland's surface, estimated subsurface production in the area (1,461 g/m^2) far outweighed its aerial counterpart. The large subsurface production value is in part a result of the continuous development of new adventitious roots as aerial stems are buried by accumulating peat. The annual net production for all nonvascular species (55.4 g/m^2) was small compared with the total for vascular species (1,777.5 g/m^2), with 82% of the vascular production associated with subsurface plant components. This total annual net production of bog vegetation is significantly higher than the values obtained by other workers. It reflects a larger value for subsurface biomass in the net production of peatland vegetation than had previously been assumed would be the case.

1. **LAVIGNE, M.B.** and **R.S. van NOSTRAND**

2. 1981

3. **Biomass equations for six tree species in central Newfoundland.**

4. Environment Canada, Canadian Forestry Service, Newfoundland Forest Research Centre, St. John's, Newfoundland. Information Report N-X-199. 51 p

5. a. **Canada; Index map NM-21/22; Newfoundland; B.28a, B.29**

   b. **Aspen, white birch, balsam fir, larch, black spruce, white spruce**

   c. **Biomass (tree)**

6. **This report describes the first work in Newfoundland to produce reliable biomass prediction equations. Data were collected for the six major tree species in central Newfoundland: *Picea mariana*, *Picea glauca*, *Abies balsamea*, *Larix laricina*, *Betula papyrifera* and *Populus tremuloides*.**

Equations to predict total and component above-ground biomass (oven dry), using breast-height diameter squared times total tree height (D^2H), are listed below for each of the six species.

Component	Equation
Balsam fir	
Total	$1.17894 + .01970\ D^2H$
Bole	$.29193 + .01473\ D^2H$
Branches	$-.00182 + .00269\ D^2H$
Foliage + twigs	$.88883 + .00228\ D^2H$
Black spruce	
Total	$3.47880 + .02368\ D^2H$
Bole	$.68337 + .01844\ D^2H$
Branches	$.31072 + .00319\ D^2H$
Foliage + twigs	$2.48471 + .00205\ D^2H$
White spruce	
Total	$2.85965 + .02349\ D^2H$
Bole	$.60394 + .01633\ D^2H$
Branches	$.27815 + .00378\ D^2H$
Foliage + twigs	$1.97756 + .00338\ D^2H$
Larch	
Total	$1.22073 + .02086\ D^2H$
Bole	$.25838 + .01715\ D^2H$
Branches	$.02713 + .00282\ D^2H$
Foliage + twigs	$.93522 + .00089\ D^2H$

Continued ...

Component	Equation
White birch	
Total	$1.20385 + .02506\ D^2H + .000000280\ (D^2H)^2$
Bole	$.39075 + .02144\ D^2H + .000000063\ (D^2H)^2$
Branches	$.24219 + .00223\ D^2H + .000000225\ (D^2H)^2$
Foliage + twigs	$.97091 + .00139\ D^2H - .000000008\ (D^2H)^2$
Trembling aspen	
Total	$.54972 + .01987\ D^2H$
Bole	$.24198 + .01691\ D^2H$
Branches	$-.04929 + .00242\ D^2H$
Foliage + twigs	$.35703 + .00054\ D^2H$

1. **LEMIEUX, Guy L.**

2. 1961

3. An evaluation of Paterson's CVP index in eastern Canada.

4. Canada, Department of Forestry, Forest Research Branch, Ottawa. Technical Note No. 112, 11 p

5. a. Canada; Index maps (all in New Brunswick and Quebec); All boreal forest sections in New Brunswick and Quebec

   b. Black spruce

   c. Climate/growth (direct relationships, latitude), Climatic variation (regional), Growing season (length)

6. This paper evaluates Paterson's CVP index (climate, vegetation and productivity) for Quebec and New Brunswick. The CVP index is based on the principle that potential productivity of a given region is controlled by the following factors; heat, humidity, length of growing season, intensity of potential evaporation and transpiration. These factors were integrated into the following numerical index:

$$I = Tv/Ta \times P \times G/12 \times E/100$$

The components of the formula are described as follows:

1. The effect of heat is best characterized by the relation Tv/Ta where Tv is the mean temperature in degrees centigrade of the warmest month and Ta is the difference in degrees centigrade between the mean temperatures of the warmest and coldest months. Tv is the numerator because of its positive influence on growth; Ta is the denominator because the greater its value the less the total annual production of wood by trees.

2. Humidity (P) is accounted for by annual precipitation (mm).

3. Evapotranspiration intensity (E) is conditioned not only by temperature, but also by intensity of solar radiation which is related to latitude. To evaluate this intensity at any given point, the equation E = 100 Rp/Rs is used, where Rp is radiation at the pole and Rs radiation at the latitude of the place under consideration, both expressed in 10^3 g cal/cm^2/min.

4. The growing season (G) is expressed simply as number of months. In boreal and cold temperate climates, Paterson chose empirically to consider as growing season the number of months with an average temperature equal to or higher than 3° C.

Paterson originally developed the CVP index with data from 41 meteorological stations, half of which were in Sweden and the others from

Continued ...

locations repesentative of the main vegetation zones of the earth; his main purpose was to find a formula that would give the same index value at the limit of tree occurrence, whether at the southern edge of the tundra or the northern edge of the steppe. On a worldwide basis, the regions separated by this formula correspond fairly well with Köppen's climatic zones.

The CVP index was calculated by the author for 152 stations in the provinces of Quebec and New Brunswick. There was a good correlation between the values of the index, Köppen's climatic zones, and local forest regions. The index values for the tundra are less than 25, between 25 and 90 for semi-open boreal forest, 90 to 160 for closed boreal conifer forest, and from 160 to 250 for deciduous hardwood forest. A few exceptional values in each region were due mostly to high precipitation which influences the formula significantly.

Productivity data were not available for all stations in Quebec and New Brunswick where climatic information was available. The author chose black spruce stands on mesic sites for comparison. Gross increment values were not available, so net increment values were used to estimate gross increment. An even-aged black spruce stand of good density (185 to 190 ft^2 basal area/acre) has at 90 yr a net mean annual increment of 50 to 55 ft^3/acre/yr, while the CVP index indicates 42 to 57 ft^3/acre/yr of gross increment.

The author suggested that slight modification may improve the formula for use in boreal regions. For example, the amount of annual precipitation in the form of snow is largely lost in spring runoff and does not contribute to the water supply of plants. The amount of precipitation during the main part of the growing season (May, June and July) may be more appropriate. Proper evaluation of the length of the growing season is also difficult, but a good approximation can be attained through coupling of meteorological data with phenological observations. The frost-free period is useful in agriculture, but of limited value in forestry. Also, expression of "G" in weeks or days instead of months might show a better continuum of values along a geographical gradient.

The author stressed that the CVP index is a climatic index, meant only to give an idea of the forest productivity of the various climatic regions of the world, and as such the formula must remain based on climatic data alone. It was never meant to be used for a regional site classification and any attempt to introduce the soil factor into it completely destroys the purpose of the formula. The CVP index is a general formula that can be very useful in economic geography and general forestry statistics where an estimate of the potential productivity of large inaccessible and non-inventoried areas is needed. It will never replace a local site classification based on detailed ecological studies combined with remeasurements of permanent sample plots to evaluate local productivity.

1. LETTAU, H. and K. LETTAU

2. 1975

3. Regional climatonomy of tundra and boreal forests in Canada.

4. IN: G. Weller and S.A. Bowling, Editors, Climate of the Arctic, Twenty-fourth Alaska Science Conference, p. 209-221.

5. a. Canada; Index maps NO-15, NN-15; Manitoba; B.5, B.22a

   b. Nil

   c. Climate (insolation), Climatic variation (regional)

6. Climatonomy is a basic study of the physical forces by which a planetary surface gains, stores, and loses its moisture and heat during the course of the seasons. This study describes an experiment of climatonomical modelling of tundra, near Baker Lake (65 00 N, 95 00 W), open tundra forest near Churchill, Manitoba (58 00 N, 94 00 W) and closed canopy boreal forests in Manitoba near 55 00 N, 95 00 W. The model predicted annual means and month-to-month variations of two basic response functions: exchangeable soil moisture and surface temperature. The model is explained in detail in this paper. The authors state that the system of climatonomy permits the singling out of selected input or process parameters, simulation of changes to various parameters, and assessment of the resulting response fluctuations with other conditions either remaining unchanged or affected by physical feedback.

For the open forest and closed forest the following model-generated averages of heat fluxes were developed:

Average heat flux (ly/day)

	May	June	July	August	September	Annually
Open forest	143	235	246	168	44	49
Closed forest	118	209	209	165	62	56

1. LIETH, H.

2. 1972

3. Modelling the primary productivity of the world.

4. Nature and Resources 8:5-10

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb, moss/lichen), Climate/growth (direct relationships, latitude)

6. Maps of world primary productivity predicted from average annual precipitation and average annual temperature are compared in this article. Annual dry matter production (P, measured as $g/m^2/yr$) was predicted from mean annual temperature (T, °C) by the regression:

$$P = \frac{3000}{1 + e^{1.315 - 0.119T}}$$ (where e = natural log base).

Productivity was predicted from mean annual precipitation (N, measured as mm) by

$$P = 3000\ (1 - e^{-0.000664\ N})$$

Included in this article are the following estimates for net primary productivity and energy fixation, for the boreal forest, total terrestrial area of the earth and for the total earth, based on 1950 data:

	Boreal forest	Total terrestrial area	Total earth
Size, $10^6 km^2$	12.0	149.0	510.0
Net primary productivity			
Range, $g/m^2/yr$	200-1,500	-	-
Approx. mean, $g/m^2/y$	500	669	303
Total for area, $10^9 t$	6.0	100.2	155.2
Combustion value kcal/g	4.8	-	-
Annual energy fixation			
10^4 cal/m^2	2.4	-	-
10^{18} cal for total area	28.8	426.1	686.9

1. LIETH, H.

2. 1974

3. Primary productivity of successional stages.

4. IN: R. Tüxen, Editor in Chief, Handbook of Vegetation Science. Part VIII, Vegetation Dynamics, (R. Knapp, Ed.), Dr. W. Junk b.v., Publishers, The Hague, Netherlands. p 185-194

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb)

6. Based on a review of world literature, the author examined the question of whether successional stages are more productive than mature (climax) stages of vegetation development. Although no data are presented specifically for boreal forests, trends to be expected during development of forest ecosystems are summarized in the table below.

Ecosystem attributes	Successional stages	Mature stages
Community energetics		
Gross production/community respiration (P/R ratio)	Greater or less than 1	Approaches 1
Gross production/standing crop biomass (P/B ratio)	High	Low
Biomass supported/unit energy flow (B/E ratio)	Low	High
Net community production (yield)	High	Low
Food chains	Linear, predominantly grazing	Weblike, predominantly detritus
Community structure		
Total organic matter	Small	Large
Inorganic nutrients	Extrabiotic	Intrabiotic
Species diversity-variety component	Low	High
Other attributes		
Nutrient exchange rate between organisms and environment	Rapid	Slow
Role of detritus in nutrient regeneration	Unimportant	Important
Internal symbiosis	Undeveloped	Developed
Nutrient conservation	Poor	Good
Stability (resistence to external perturbations)	Poor	Good
Entropy	High	Low

Continued ...

In general, the increase of biomass (standing crop) at any given location on earth is largely dependent on environmental forces. In places where tundra or grassland forms the climax vegetation, the standing crop will never reach more than 5 to 25 t/ha. This level may be reached within 3 to 15 years. In places where forest formations form the climax, values are much higher, with values of 400 t/ha in a little over 200 years for oak forest in the temperate zone. Three-fourths of this value is reached within 100 years. Tropical forests can accumulate 120 t/ha within 10 years. One of the main characteristic differences between perennial herbaceous and perennial forest vegetation is the fact that herbaceous vegetation maintains about 50% of the total maximum biomass measured each year in the underground root system. Forest, in contrast, rarely goes as high as 25% investment in root biomass.

1. LIETH, Helmut

2. 1975

3. Primary production of the major vegetation units of the world.

4. IN: H. Lieth and R.H. Whittaker, Editors, Primary Productivity of the Biosphere, Springer-Verlag, New York. p. 203-215

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb, moss/lichen)

6. Included in this article is a discussion of the relationship of productivity to biomass, assimilatory surface and chlorophyll content. The ranges of values for these factors have been compiled and are represented as follows for the boreal forest, tundra and warm temperate mixed forest:

Vegetation unit	Mature biomass (kg/m^2)	Leaf area index or assimilating surface (m^2/m^2)	Total chlorophyll (g/m^2)
Warm temperate mixed forest	24.0	5.0 - 14.0	3.0 - 8.0
Boreal forest	20.0 - 52.0	7.0 - 15.0	1.4
Tundra	0.1 - 3.0	0.5 - 1.3	0.4 - 0.6

Knowledge of biomass is essential in understanding nutrient pools in organisms as part of the study of nutrient cycling and biogeochemistry. The higher the productivity of a community, the greater the amount that is likely to accumulate as biomass. The correlation is loose, however, and is not widely useful for the estimation of productivity itself. Biomass is much affected by ages of the dominant plants and these ages differ in successional communities. Grasslands and other fire-susceptible communities, even those that are highly productive, tend to have low biomass compared with other communities. Biomass ranges for terrestrial communities are generally from 0.1 to 5 kg/m^2 in many grasslands, desert scrubs, and tundra communities; 5 to 20 kg/m^2 in many woodlands of small trees, shrublands and young forests, and 20 to 60 kg/m^2 for many mature forests.

Leaf area index is an important dimension related to production, for it defines the leaf area through which the gaseous exchange of photosynthesis must occur. Leaf area indices are correlated with productivity, but only roughly so, and in a way that does not permit effective prediction of production from the indices. Evergreen communities generally have higher leaf area indices than deciduous ones of similar productivity. Most gymnosperm forests have high indices. A wide variety of communities have leaf area indices of 3 to 6 m^2 of leaf surface area/m^2 land surface area if they are deciduous, up to 8 m^2/m^2 if evergreen, and up to 16 m^2/m^2 for conifers.

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Chlorophyll content may appear to be the community property most directly relevant to the prediction of productivity. However, the correlation is loose and the efficiency of energy capture by chlorophyll differs widely within and between communities. Ranges of chlorophyll content are convergent among communities. The span of 2 to 6 g chlorophyll/m^2 of ground surface would include a range of productive communities, and 0.4 to 2 g chlorophyll/m^2 should include most others except those of extreme environments.

The author stressed that, in any landscape, primary productivity varies over short distances, in response to differences in topography, water availability, soil quality and successional stage.

1. LIETH, H.

2. 1978

3. Primary productivity in ecosystems: comparative analysis of global patterns.

4. IN: H.F.H. Lieth, Editor, Patterns of primary production in the biosphere, Benchmark Papers in Ecology/8, Dowden, Hutchinson and Ross, Inc. Stroudsburg, Pennsylvania. p. 300-321

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb, moss/lichen), Climate/growth (direct relationships, latitude), Growing season (length)

6. The author developed correlation models based on a limited set of actual productivity measurements paired with environmental data, and then constructed regression equations to predict net primary productivity (P, measured in t/ha/yr). Four models of this type have been constructed as follows:

   1. $P = -1.57 + 0.0517\ S$
      (where S = photosynthetic season, days)

   2. $P = 3000\ (1 - e^{-0.00664N})$
      (where N = mean annual precipitation, mm and e = natural log base).

   3. $P = \dfrac{3000}{1 + e^{1.315 - 0.119T}}$
      (where T = mean annual temperature, °C, and e = natural log base).

   4. $P = 3000\ (1 - e^{-0.0009665\ (E-20)})$
      (where E = actual annual evapotranspiration, mm, and e = natural log base).

The author noted that a variety of models have been presented for expressing the relationship between net primary productivity and the length of the growing season. One of these models was described as follows:

Rybchikov's model, where $Kp = \dfrac{W\ Tv}{36\ R}$

in which Kp = productive potential, W = annual effective precipitation, Tv = length of growing season as multiples of 10 day units and R = annual radiation. The units of measure were not specified by the author.

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Included in this article is a table that lists net primary productivity of different biomes within the world. Productivity estimates for the boreal forest, in comparison with total terrestrial productivity and total global productivity are given as follows:

	Total area $10^6 km^2$	Mean net primary production $kg/m^2/yr$	Mean annual energy fixation $10^6 cal/m^2$	Total annual product. $10^9 t$	Total annual energy fixation $10^{18} cal$
Boreal forest	12.0	0.65	3.0	7.8	36.0
Total terrestrial	149.0	-	-	121.7	535.3
Total global (including marine)	510.0	-	-	176.7	793.5

1. LONGLEY, Richmond W.

2. 1972

3. The climate of the prairie provinces.

4. Environment Canada, Atmospheric Environment, Toronto, Ontario. Climatological Studies No. 13. 79 p

5. a. Canada; Index maps (all in Alberta, Manitoba and Saskatchewan); All boreal forest sections in Alberta, Manitoba and Saskatchewan

   b. Nil

   c. Climate (precipitation, temperature), Climatic variation (temporal, temperature, precipitation)

6. This climatic description was presented under several headings: basic elements of climate; physiography; spring weather, summer weather; autumn weather; winter weather; climate during the year; and climatic regions and climatic changes. In the section dealing with climatic changes, the author pointed out that during the 100 yr in which man has developed the agriculture of the prairies, the climate has shown no dramatic changes. Nevertheless, the records show fluctuations that influence agriculture. The author's graph of the 10-yr running mean temperature for Beaverlodge, Alberta, shows that the cycles of warm and cold can be accentuated in a particular district even though they are not readily apparent elsewhere. For example, there was an extreme dip in temperature at Beaverlodge during the 1930's that was not apparent in the curve for the prairies as a whole. The diagram for the entire prairie region showed that temperatures rose from the late 1800's until about 1910, the rise amounting to about 1.5° F. Between 1920 and 1950, the mean stayed between 37 and 38° F, with the warmest decade being 1925-1934. The years between 1945 and 1960 were generally cold, and so the running mean dropped to 36° F for the 1946-1956 period. These swings can be seen to have significance if one considers some of their effects. A drop of 2° F during the growing season reduces the frost-free season by 20 to 30 days, and the growing degree-days by 200 or more units. Such a change cannot fail to have an appreciable adverse effect on the agriculture of an area.

In the more northerly districts of the prairie provinces, there was a rise in rainfall from the drought of the 1890's to a wet period ending about 1917. Otherwise precipitation has remained relatively uniform. The records for Beaverlodge in the Peace River District, which began in 1915, show much the same uniformity. Some meteorologists are convinced that the cool dry period of the late 19th century was a result of dust in the high atmosphere from a volcano in the Pacific in 1883. The author pointed out that meteorologists are not yet agreed on the causes of the major changes in climate and it is not considered possible to forecast what the weather will be like in the coming decade.

1. LONGLEY, Richmond W.

2. 1977

3. Climatic change as it affects Alberta and the other prairie provinces.

4. Alberta Environment, Research Directorate, Edmonton, Alberta. 33 p

5. a. Canada; Index maps (all in Alberta, Manitoba and Saskatchewan); All boreal forest sections in Alberta, Manitoba and Saskatchewan

   b. Nil

   c. Climate (temperature), Climatic change (hypotheses, proxy data), Climatic variation (regional, temporal, temperature, precipitation)

6. Climate by definition is average weather. Although we know that weather is variable, we usually consider that the climate stays constant. The line of demarcation between a constant climate and variable weather is not easy to establish. A realistic compromise is to say that the climate is the average weather for a generation. Government weather services publish climatic means for a base of 30 yr. A common method for examining climatic change is to compute 10-yr running means of recorded climatic variables. The period of 10 yr is too short to establish a reliable normal for many meteorological variables, particularly in the temperate and polar regions. But the changes in the average through the period of record give clues to the changes that have occurred.

The author reviewed several suggested causes of recent climatic changes in the prairies including: 1) primary variations of solar radiation; 2) volcanic ash and dust; 3) cloudiness in the atmosphere; and 4) carbon dioxide in the atmosphere. To these should be added three changes that mankind has made or could make that might affect the climate: 1) additional dust added to the atmosphere; 2) destruction of ozone in the stratosphere; and 3) clearing of land for agriculture.

Although mankind cannot measure the solar constant with the accuracy necessary to relate it to climatic change, there is reason to believe that it changes when sun spots occur on the sun's surface. Meteorologists have compared world temperatures with sun-spot numbers and have concluded that with a moderate number of spots, the temperature rises, but the increase is less when the number of spots is high. Analyses of sun spots and auroral activity during the past 400 yr have revealed that sun spots were seldom seen during the 17th century. For a period of 32 yr, no observation was reported in the northern hemisphere. This period with few or no sun spots was part of the cold period called the Little Ice Age. No hypothesis has been advanced to explain the absence of sun spots or to explain how frequently a period with very few spots occurs.

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Longley, R.W. 1977. Continued

The author's examination of hypotheses isolated two factors which seem to influence the climate and which are such that we can predict their future changes. One of these factors is the amount of carbon dioxide in the atmosphere. This amount has been rising and is expected to continue to rise. The overall effect is expected to be a slightly higher temperature over the world during the next 50 yr.

The second factor is the sun-spot cycle which has had an effect on temperatures in more southerly latitudes in the prairie provinces. It may have caused the cycle of rainfall in the southern areas of the provinces. In one cycle there was the drought of the 1930's. Its severity was a result partly of lack of moisture, but also partly because of the high temperatures and the resultant additional evaporation.

The cold weather of the 1880's and 1890's was caused, at least partially, by the volcanic eruption of Krakatoa and other volcanoes. During those years, rainfall was extremely low, temperatures were low, and frost-free periods were short. Farming as has been practised over the past half century would have been impossible then. The author forewarns that we must expect volcanic eruptions to reduce the earth's temperature for short or longer periods in the future, but it is not possible to predict when or where they will occur. Lacking criteria for prediction of climatic changes from variations in sun-spot activity or volcanic activity, the author suggested that the last 50 yr gives the best guide to the climate expected in the coming years.

1. LYDOLPH, Paul E.

2. 1977

3. Some characteristics of the climate of the USSR with a direct bearing on human activity.

4. Soviet Geography 18:145-162

5. a. U.S.S.R.

   b. Nil

   c. Climate (air masses, insolation, precipitation, temperature)

6. At high latitudes in winter there is little insolation (solar heating) because of the very short or even nonexistent days and the low angles at which the sun's rays hit the earth. Since quantities of insolation are small everywhere, there is not much variation from one latitude to another. Also, because of a fresh snow cover throughout the winter, what little sunlight might fall on the earth at these latitudes is largely reflected and so does not act as a source of heat for warming the surface. Therefore, latitude is of little consequence in temperature distributions throughout a great portion of the U.S.S.R. during the winter. Isotherms in the western part of the country run almost north-south in winter, while in the eastern part of the country they form concentric circles around the so-called "cold pole of the world" in the river valleys east of the Lena River. This pattern contrasts greatly with the summer pattern, which shows a much greater latitudinal control.

The author pointed out that it is usually stressed that latitudinal differences in insolation, and hence temperature, are greater in winter than in summer. But this is true only in the lower latitudes from the equator to 50° or 55°. Beyond that, the slight effects of insolation and the high albedo (reflectivity) of the snow cover in winter rule out any latitudinal influence on temperature. Therefore, the temperature distribution that exists is generally explained by land-water differences and local effects, such as topography.

The single most important control on temperature over much of the U.S.S.R. in winter is distance from the Atlantic Ocean, in spite of the fact that none of the region is close to the Atlantic proper. Throughout much of European U.S.S.R. there is actually a positive temperature anomaly in winter, which makes much of European U.S.S.R. abnormally warm for its latitude. Unfortunately, the latitude is fairly high, so that the winters are still severe.

The high latitude also results in very uneven lengths of seasons. Spring is essentially missing, since most of the increasing heat from insolation and advection of warm air masses in spring is utilized to melt the snow,

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thaw the topsoil, and evaporate the excess moisture on the land. With heat being thus utilized, little heat is left to increase surface air temperatures much above freezing. By the time the melting and evaporation have been accomplished, the year is well along toward the summer solstice, and then surface air temperatures rise to rather high values under the influence of almost 24-hour daylight. In autumn, temperatures do not drop off nearly as rapidly since there is no snow cover to be contended with. In fact, as the land begins to freeze in early winter the latent heat released by the freezing process may prolong relatively high autumn air temperatures for a time. Therefore, the summer temperature curve is not only short in duration and rather peaked in magnitude, but also asymmetrical, with a more rapid rise in early summer and a gentler decline in late summer.

High latitude also tends to induce lags in summer rainfall maxima in continental locations. Convective activity, which is the cause of much summer precipitation in continental interiors, lags later and later into summer as one proceeds poleward because of the delaying effects of snow cover and frozen ground, which will not allow the surface air temperature to warm much until all the thawing has been accomplished. Thus, the precipitation maximum throughout much of the U.S.S.R. lags from June in the southern Black Sea-Caspian Sea-central Kazakhstan zone to July in much of the central part of the country and to August in a broad strip inland from the Arctic coast.

The high mountains all along the southern border of the U.S.S.R. rule out intrusion of warm moist air masses from subtropical latitudes and add to the continentality, which is expressed in terms of reduced precipitation. The east-west orientation of the mountains also causes a moisture zonation that is perpendicular to the one in eastern North America. In eastern North America, the temperature zones run generally east-west, while the moisture zones run north-south. In the U.S.S.R. they both run east-west. Thus, in North America the moisture and temperature gradients are perpendicular to each other, while in the U.S.S.R. they are not. This means that the U.S.S.R. offers fewer choices of moisture and heat combinations than does the eastern half of the United States; in the U.S.S.R. th zones tend to be limited to either cold and wet or hot and dry.

The author suggested that man-made improvements to heat resources may be brought about in the northern part of the U.S.S.R. by drainage, which would eliminate much of the evaporation of moisture from the surface that is using up heat in the form of latent energy. Therefore, surface soil and air temperatures should rise, and this should enhance crop growth on drained land that was too cool and moist for crop growth before. Under a program for improvement of the nonchernozem region, announced as one of the main thrusts of the 15-yr plan (1976 to 1990), about 10 million ha are to be drained in north-central European Russia. Among other things, crop yields are expected to rise in this area by 2.5 times during the 15-yr period.

1. MacLEAN, David A. and Ross W. WEIN

2. 1976

3. Biomass of jack pine and mixed hardwood stands in northeastern New Brunswick.

4. Canadian Journal of Forest Research 6:441-447

5. a. Canada; Index map NL-20; New Brunswick

   b. Jack pine

   c. Biomass (tree)

6. A series of pure jack pine and mixed hardwood stands of fire origin and ranging in age from 7 to 57 yr were studied in northeastern New Brunswick to determine biomass accumulation as the forest recovers after fire. This article presented allometric equations for prediction of dry matter distribution in eight tree species and estimates of above-ground tree biomass (excluding roots) of 12 jack pine stands and 11 mixed hardwood stands. Although the study area was within the Acadian Forest Region rather than the Boreal Forest Region, jack pine stands such as those documented by the authors are common in southern boreal forests as well. The information annotated below was selected to focus on jack pine and emphasis was placed on the stand biomass data rather than regression equations for prediction of biomass of individual trees.

The relationship between above-ground tree biomass and stand age showed a generally increasing biomass accumulation over the 40-year time span examined. However, Hegyi (1972) showed that a substantial amount of biomass variation on jack pine stands could be explained in terms of variation in the degree of stocking, or stand density. Examination of stand density data (stems per hectare) showed large differences in stocking in the sample stands in this study also, and therefore an adjustment to stand biomass was made using the stocking ratio, as in Hegyi (1972). This gave an adjusted dry matter for the stand as summarized in the last column in the table on the following page.

The authors found that 15 yr after fire, jack pine showed a relatively low above-ground tree biomass of 1 to 2 t/ha, whereas hardwood stands were 8 to 10 t/ha. By an age of 30 yr, however, jack pine biomass was about 50 t/ha and the hardwood was about 40 t/ha. Therefore, initially hardwood stands showed higher productivity, but in the age range of 20 to 30 yr, jack pine demonstrated greatly increased production, surpassing the hardwoods. Jack pine stands in the 20 to 25 yr age range and fire-regenerated hardwood stands older than 37 yr were not available for study.

Continued ...

MacLean, D.A. and R.W. Wein. 1976. Continued

The authors' summary of above-ground biomass for 12 jack pine stands is listed in the table below. Because of the lack of normal yield tables for young stands, adjusted dry matter could not be calculated for the 13 and 16 year stands.

Stand age (years)	Density (stems/ha)	Basal area (m^2/ha)	Actual dry matter* (10^4 kg/ha)	Adjusted dry matter (10^4 kg/ha)**
13	3,040	0.2	0.078 (0.031)	-
16	2,320	0.3	0.190 (0.075)	-
29	3,040	13.5	4.278 (0.390)	5.093
29	6,560	24.7	8.013 (0.292)	5.216
31	2,200	13.0	3.958 (1.127)	5.159
37	2,520	20.4	6.574 (1.060)	6.061
37	4,840	26.7	8.394 (0.704)	5.907
38	2,600	11.5	3.566 (0.647)	5.891
40	6,000	28.2	9.110 (0.573)	6.526
44	3,440	28.4	8.328 (0.795)	5.929
49	3,480	17.8	5.696 (1.213)	6.742
57	2,440	24.8	7.511 (0.367)	6.677

* Standard error of estimate given in brackets
** Actual dry matter x stocking ratio

Hegyi (1972) studied dry matter distribution in jack pine stands in northern Ontario and derived an accumulation curve similar to the authors' jack pine data. His stands ranged up to 100 yr of age but showed the same general type of curve as found in this study. For stands in the age range of 25 to 60 yr, the above-ground dry matter was higher on the Ontario stands (range of about 60 to 110 t/ha versus 50 to 70 for the New Brunswick stands). This may be accounted for in terms of site class, however, since Hegyi's stands were of site classes 1 and 2, and those in the present study were all site class 3.

The present study considered only the above-ground biomass of the forested stands because of the difficulties in determining root dry weight. Morrison (1974) determined the dry matter content of roots for eight trees in a 30 to 35 yr old jack pine stand in northern Ontario for two site classes with high and low stocking. Root biomass was reported as about 10,000 to 16,000 kg/ha dry weight (Morrison 1974), whereas the approximate above-ground biomass for a 30 yr jack pine stand in the present study was 50,000 kg/ha. Therefore an appreciable portion of stand biomass is found in the roots.

1. MacLEAN David A. and Ross W. WEIN

2. 1978

3. Litter production and forest floor nutrient dynamics in pine and hardwood stands of New Brunswick, Canada.

4. Holarctic Ecology 1:1-15

5. a. Canada; Index map NL-20; New Brunswick

   b. Aspen, jack pine

   c. Biomass (tree, shrub/herb)

6. Biomass and nutrient transfer (N, P, K, Ca, Mg) of overstory (branches and leaves) and understory litter fall were examined over a two year period in four jack pine stands aged 16, 29, 49 and 57 years and four mixed hardwood stands aged 7, 17, 20 and 29 years. The stands sampled were located at similar elevations in a 15 x 30 km area of northeastern New Brunswick. The data are not strictly representative of the boreal forest region, since the study area lies within the Acadian forest region. However, jack pine stands such as those sampled by the authors are a characteristic feature of many areas within the boreal forest region. The hardwood stands sampled were a mixture of red maple, white birch, pin cherry and trembling aspen. The climate of the study area is temperate-humid due to the proximity of the Atlantic Ocean, and consists of short warm summers and long, cold winters, with mean temperatures of -13° C in January and 18° C in July. The mean annual precipitation is only 90 cm, including a heavy mean annual snowfall of 270 cm.

A summary of total overstory and understory biomass is given in the table below.

Stand age (yr)	Biomass (kg/ha) Overstory	Understory
Jack Pine		
16	1,900	4,610
29	42,780	1,730
49	56,960	3,590
57	75,110	2,330
Hardwood		
7	8,230	1,260
17	7,080	3,360
20	29,680	3,010
29	40,970	1,320

A substantial amount of ground vegetation exists on these stands, ranging from about 1,300 to 4,600 kg/ha. With this large biomass of generally

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high-nutrient content material, much of which is deposited on the soil surface annually, it is obvious that the understory litter fall plays an important role in the nutrient cycle. Numerous studies have estimated the litter fall of understory plants as equal to their late-season standing crop. This is probably an adequate estimate in the case of herbaceous (non-woody) species, provided that some estimate of the dry-weight loss, due to senescence, is incorporated. If deciduous woody species are present, however, the standing crop will greatly overestimate annual litter fall, and it becomes necessary to determine the percentage of the standing crop annually deposited as litter fall.

Litter fall from the combined understory layers ranged from 820 to 1,540 kg/ha in the pine stands, and from 890 to 2,520 kg/ha in the hardwood stands. No clear trends of biomass changes with stand age existed, although on the pine stands, herb layer litter fall generally decreased with increasing stand age whereas the reverse occurred in the shrub layer.

Long-term studies have shown wide annual variation in litter fall. Bray and Gorham (1964) reviewed a number of studies where litter fall was monitored for over four years, and found that ratios of maximum to minimum yearly litter fall ranged up to 2.7 for angiosperms and 5.1 for gymnosperms. This was partly borne out by the relatively high year-to-year variation encountered on several of the stands in this study, over just a two-year period. Ratios of maximum to minimum overstory litter fall during the two years sampled were 5.5 for the youngest pine stand, and 1.4 to 1.5 for the three oldest hardwood stands, although the other stands had similar values during the two years.

Organic matter residence times ranged from 24 to 53 yr in the pine stands, versus 12 to 28 yr in hardwood stands. These residence times correspond to fractional annual turnovers of 1.9 to 4.2% and 3.6 to 8.2%, respectively. It is not surprising that turnover is slower on the pine stands, since pine needles are more resistant to decomposition than the hardwood species. A surprising result is that the residence time of organic matter generally decreased with stand age among the four jack pine stands. The opposite usually would be thought to occur, with decomposition rates highest in a younger stand. The fire origin of these stands has probably caused this inverse order, because fire generally kills the trees in this region but does not consume them completely. Over the ensuing years, large amounts of slow to decompose woody material are added to the forest floor, which increases the forest floor mass and effectively increases the residence time.

1. MAINI, J.S.

2. 1966

3. Phytoecological study of sylvotundra at Small Tree Lake, N.W.T.

4. Arctic 19:220-244

5. a. Canada; Index map NP-12/13; District of Mackenzie; B.27

   b. White birch, larch, black spruce, white spruce

   c. Treeline studies (growth)

6. The transitional zone between treeless tundra and the circumpolar coniferous forest zone (taiga) is known as sylvotundra, lyesotundra or wooded tundra. The purpose of this study in the central portion of the North American sylvotundra was to make a quantitative evaluation of representative plant communities in relation to physiographic features. The study area was located at 60 01 N, 105 01 W at Small Tree Lake, Northwest Territories. The author pointed out the significance of this study location because of the distributional limits of plant taxa, which can be viewed as mobile migration fronts; extremes in climatic conditions often play an important role in limiting plant extension into new territory.

Among the three forest stands and the parkland, the stands in extremely moist and dry-mesic conditions had a lower density of tree stems per acre than those in intermediate conditions. The wet and dry-mesic stands had, respectively, 172 and 48 trees per acre, while in the wet-mesic and mesic stands densities were, respectively, 281 and 275 trees per acre. Although the average basal area per tree did not differ appreciably among the wet, wet-mesic, and mesic stands, the trees were relatively much larger in the dry-mesic stand. Tree dominance (basal area per acre) in the forest stands and parkland has a trend similar to that of stand density, i.e. more under the intermediate conditions than under extreme high or low moisture conditions. Maximum height recorded in the wet-mesic, mesic, and dry-mesic habitats was 22.5, 35.0, and 37.0 ft, respectively, and maximum dbh was 5.7, 8.5, and 11.5 inches, respectively, indicating improved growth with better drainage and related topographic conditions.

The author pointed out that in the northern hemisphere the transition from closed canopy forest zone to treeless tundra is generally attributed to a gradual transition in climate. In the forest-tundra ecotone, the pattern of distribution of arboreal and non-arboreal vegetation varies in different localities and may be determined by several factors including topography, edaphic condition, microclimate, and the ecological amplitude of species. In this study, stand density (expressed as number of trees per acre) varied along the moisture gradient, as it was higher under intermediate than under extreme situations. The data show that **Picea mariana** dominated the more mesic and **Picea glauca** the drier

Continued ...

Maini, J.S. 1966. Continued

habitats. Both **Larix laricina** and **Betula papyrifera** were less significant constituents of the tree canopy, the former occurring in the wet and wet-mesic sites and the latter in the wet-mesic site only.

Presence of only a few **Picea glauca** seedlings and absence of juveniles and saplings on a ridge-top in the study area indicate favourable periods of climatic conditions that enabled survival of seedlings. Trees were absent on the flat ridge top and there was no evidence to suggest occurrence of trees in the past. Seedlings, when established, do not attain tree size and are possibly exterminated by strong winds, unfavourable weather or extreme climatic conditions. The distribution pattern of **Picea glauca** trees at Small Tree Lake is similar to that described at the upper Firth River valley in the Yukon where the species extends along the lower two-thirds of the south-facing slope while the north-facing slope is treeless and occupied by upland tussock tundra.

Data and field observations show that the boundaries between forests and treeless areas at Small Tree Lake are semi-permanent and that the distribution of various vegetation types is determined by topography. Physiognomically, as well as floristically, low-lying areas along the lake shore are predominately forest vegetation while exposed northerly and easterly slopes are treeless with an appreciable proportion of arctic plants.

1. **MAJOR, J.**

2. 1974

3. Biomass accumulation in successions.

4. IN: R. Tüxen, Editor in Chief, Handbook of Vegetation Science. Part VIII, Vegetation Dynamics, (R. Knapp, Ed.), Dr. W. Junk b.v., Publishers, The Hague, Netherlands. p 195-204

5. a. Alaska; U.S.S.R.

   b. Alder, Scots pine

   c. Biomass (tree, shrub/herb)

6. This review of literature contains several references to biomass accumulation rates in vegetation types of the boreal region.

Alaskan researchers documented biomass and N accumulation in sandbar succession along the Tanana River near Fairbanks (64 45 N, 148 00 W) in an area that has a very continental climate characterized by the following features: annual mean temperature, -3.6° C; annual range of monthly means, 38.8° C; precipitation, 305 mm/yr, potential evapotranspiration, 440 mm/yr; actual evapotranspiration, 280 mm/yr. The vegetation consisted mostly of **Alnus incana** ssp. **tenuifolia** with willows (**Salix brachycarpa** ssp. **nithoclada** and **S. alaxensis**). Over 20 yr, dry weight of biomass accumulated at a linear rate of 350 $g/m^2/yr$. An additional 100 $g/m^2/yr$ accumulated as dead, standing organic matter.

Rodin and Bazilevich (1967) summarized biomass data for 51, 83, and 115 yr old mixed spruce forests on well-drained soils near Veliki Luki in European Russia (56 21 N, 30 32 E), where the climate was characterized by: annual mean temperature, 4.8° C; annual range of monthly means, 24° C; annual precipitation, 543 mm; potential evapotranspiration, 547 mm/yr; actual evapotranspiration, 466 mm/yr. The rate of biomass accumulation was 115 $g/m^2/yr$ for the period of record but was 335 $g/m^2/yr$ overall. Spruce-green forest or feather moss forest occurs in the same region but on more level terrain. Its rate of biomass accumulation after an initial lag to 20 yr was 486 $g/m^2/yr$, decreasing after 70 yr, with an overall rate of 338 $g/m^2/yr$ at age 93. **Pinus sylvestris** in the Smidovich reserve (54 55 N, 43 15 E) reached 438 $g/m^2/yr$, then declined after 50 yr. The overall biomass accumulation rate was 304 $g/m^2/yr$.

Data summarized by Rodin and Bazilevich (1967) indicate that old coniferous forests in the boreal region have biomass accumulation rates that range from 200 $g/m^2/yr$ in 200 yr-old spruce in the Achangelsk region of U.S.S.R. down to 60 $g/m^2/yr$ in a **Pinus sylvestris-Sphagnum** bog.

1. MAJOR, J.

2. 1974

3. Kinds and rates of changes in vegetation and chronofunctions.

4. IN: R. Tüxen, Editor in Chief, Handbook of Vegetation Science. Part VIII, Vegetation Dynamics, (R. Knapp, Ed.), Dr. W. Junk b.v., Publishers, The Hague, Netherlands. p 7-18

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb)

6. The author stressed that any given study of vegetational changes should focus on one specific level and that the various kinds of changes were associated with rather specific classes of time duration as summarized in the table below.

DURATION (years)	KIND OF CHANGE
Daily:	Daily rhythms of transpiration and photosynthesis in component species
1	Seasonal (related to the ontogeny of particular species of the community or changes in tolerances in different growth stages).
about 4	Small rodent cycles possibly related to cycling of necessary minerals from the animal to the plant population.
Few 10's.	Weather cycles producing changes in productivity, seed supply, cover or abundance of annuals.
Several 10's.	Changes in species' vitality with age or ontogenetic changes in perennials with age.
Several to many 10's.	Replacement cycles within the community, pattern and process cycles related to limited life spans of species.
100's.	Changes leading to development of a new community from the former one.
Few 100's	Microevolution caused by man's activities in some factor of the environment that produces changes in the vegetation, such as burning, fire control, mowing, or forestry.

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1,000's.	Natural changes in factors of the environment, such as changes in climate, physiography, flora or fauna, or slow modifications of soil parent material by geological processes.
Many 1,000's.	Evolution of coenoses related to changes in flora by immigration, extinction or evolution.

Natural catastrophes can break the successional pattern at any time and, since species diversity also shows a similar maximum, such perturbations are important in an evolutionary as well as a productivity sense. There is evidence, from many kinds of ecosystems, that if plant succession goes on long enough it results in less productivity and even in lower biomass in some cases.

1. **MATHEWS, J.A.**

2. 1976

3. 'Little Ice Age' palaeotemperatures from high altitude tree growth in S. Norway.

4. Nature 264:243-245

5. a. Norway

   b. Scots pine

   c. Climatic change (dendrochronology, proxy data), Treeline studies (climate)

6. The sensitivity of tree growth to climate has led to reconstruction of past climates from long tree-growth records. Growth at the treeline in mountain regions and at the polar limits of tree growth is particularly useful because, in these locations, moisture is normally adequate and growth has been shown to be highly dependent on summer temperatures. The author constructed a continuous record of summer temperature fluctuations representative of treeline conditions in the central southern Norwegian fjell since A.D. 1700. A combination of tree-ring data and information from glacier fluctuations over the same period shows short term temperature oscillations of 1.0 to 3.0° C superimposed on a long term increase in temperature of approximately 1.0° C.

Two major limitations appear to restrict the use of tree-growth variations as palaeothermometers. First, even at the treeline, it is difficult to demonstrate a sufficiently high dependence of tree growth on summer temperatures. Secondly, calculation of standardized tree-growth indices (necessary to remove the effect of tree age on growth increment) results in the elimination of longer-term trends from the tree-growth record and hence the loss of information about longer-term temperature fluctuations. The author showed that summer temperatures which are not subject to the above limitations can be reconstructed from tree growth. A Scots pine tree-growth record, previously published by Slåstad from the treeline in upper Gudbrandsdalen, and shown by him to be highly correlated with summer temperatures from the Dombås meteorological station, was analysed for its palaeotemperature implications; independent glaciological and geomorphological evidence from the Storbreen glacier, Jotunheimen, was used to adjust the record to take into account the long-term change in climate over the period of interest.

The close agreement between glacier fluctuations and tree-growth variations is explained by the fact that tree growth at the altitudinal treeline and glacier behaviour are both dependent upon summer temperature. The altitude of the equilibrium line, which divides the glacier into accumulation and ablation zones, is a climate-sensitive

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parameter and is particularly influenced by summer temperature. The information derived from equilibrium-line displacement permits calibration of tree-growth variations in terms of summer temperatures. The calibrated curve provides a continuous record of summer temperatures over the past 250 yr. At least 10 major oscillations are indicated, superimposed on a long-term temperature rise of 1.0° C since A.D. 750. Cool fluctuations reached 1.0 to 2.0° C below present temperatures; warm fluctuations were up to 1.0° C above present temperatures. These temperature fluctuations are regarded as irregular rather than cyclic, although recent work based on the Grampian Mountains, eastern Scotland, has suggested the existence of cyclic patterns in growth of Scots pine during the 20th century.

The first half of the 18th century is shown to have been at least 1.0° C cooler than the present, particularly from 1701 to 1725 when summer temperatures were on average 1.6° C below present temperatures. In contrast, the period from 1751 to 1775 was markedly warmer (less than 0.5° C below present) and corresponds well with the retreat of Storbreen and other southern Norwegian glaciers from their 'Little Ice Age' maxima reached about A.D. 1750. Renewed cooling occurred near the end of the 18th century (1776 to 1800) and continued into the 19th century (1801 to 1825), but this cooling phase was not as great as that experienced at the beginning of the 18th century. Since 1825 no period has been greater than 0.6° C below present temperatures; 1825 to 1900 was from 0.4° C to 0.6° C cooler than at present and the 20th century (1901 to 1950) is indicated as being warmer than any previous 50- or 25-yr period with summer temperatures that were on average only 0.3° C below those of 1949 to 1963.

The temperature fluctuations that have been inferred from tree-growth variations are in broad agreement with existing knowledge from other sources such as instrumental records, stable isotope ratios in ice and wood, treeline fluctuations, glacier fluctuations, the extent of arctic pack-ice, fluvio-glacial sedimentation rates, the incidence of rockfalls, avalanches and other natural disasters, vine harvest dates and crop failures.

1. MATTSON, William J. and Norton D. ADDY

2. 1975

3. Phytophagous insects as regulators of forest primary production.

4. Science 190(4214):515-522

5. a. Northern hemisphere

   b. Aspen

   c. Climate/growth (indirect influences)

6. Although this article provides little information specific to the boreal forest, it is a recent and comprehensive review of mechanisms by which insects can interact with climate/growth relationships in forests. Forest ecosystems support many kinds of phytophagous insects, but only few species cause dramatic defoliations and widespread destruction of trees. These are termed outbreak species. Four such species have recently stirred public concern in North America: the Douglas fir tussock moth, the gypsy moth, the eastern spruce budworm and the southern pine bark beetle.

Normal insect grazing (from 5 to 30% of annual foliage crops) usually does not impair annual primary production. In fact, it may accelerate growth. Although outbreaks do reduce plant production temporarily, they commonly occur in individual plants or in whole forest systems that are not particularly productive - that is, those which are under stress resulting from inadequate or excessive moisture, nutrient deficiencies, or pollution, or are senescent, having already passed their peak efficiency in biomass accumulation rates. Moreover, after an outbreak has subsided, there is evidence that the residual vegetation is more productive than the vegetation that was growing immediately before the outbreak. The authors' intent in this article was to examine the evidence for the hypothesis that insects can act as regulators of primary production and nutrient cycling and thus perform a vital function in ecosystem dynamics. The focus is on outbreak phytophages of temperate and boreal forests.

Primary production (P) can be viewed as a product of the amount of photosynthetic biomass (leaf weight, or LWT) and the average rate of net photosynthesis (RNP) or net assimilation per unit of photosynthetic biomass: P = LWT multiplied by RNP. Grazing insects influence P by directly and indirectly affecting LWT and RNP. For example, grazing by insects directly reduces LWT, but indirectly affects LWT and RNP by altering the physiological status of plants and by: 1) increasing light penetration through the foliage canopy; 2) reducing competition among plants for the abiotic flux; 3) altering the plant species composition of a community; 4) increasing the rate of nutrient leaching from foliage; 5) increasing the rate of fall of nutrient-rich litter; 6) stimulating

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the redistribution of nutrients within plants from sinks (such as boles and branches) to components such as leaves, buds, and flowers, with high turnover rates; and 7) stimulating the activity of decomposer organisms.

Therefore, to evaluate the effects of grazing by insects on primary production, one must consider: 1) intensity of grazing; 2) quantity and distribution of photosynthetic biomass; and 3) variations in the average rates of net photosynthesis under a broad spectrum of grazing and environmental conditions. Few (if any) studies of primary production have simultaneously considered all of these variables. In this article, the authors review only above-ground primary production because little is known about below-ground primary production and even less is known about below-ground grazing.

In most temperate forest ecosystems, foliage-feeding insects usually consume 3 to 8% of the annual foliage production. However, some ecosystems, such as those that support species of outbreak phytophages, have higher than average foliage consumption, which may periodically reach 100% or more of the annual forage production. Complete removal of the foliage on evergreen species represents consumption of 2 to 7 years of foliage production because most evergreen species retain annual foliage yields for several years.

One hypothesis is that primary production (P) depends less on the amount of mineral nutrients in the soil than on the speed of organic matter turnover under the forest canopy. Because insect grazers can respond to the nutrient levels in plants, nutrient availability becomes doubly important to our understanding of P. For most nutrients, the largest input is probably from the decomposition of organic matter which seems to support the stated hypothesis. Nutrient cycling is closely correlated with the rate of net primary production. Both seem to peak just before or when trees attain the so-called pole stage (7 to 22 cm diameter). The time required for this to occur depends on characteristics of the dominant tree species and fertility of the site. Trees typically attain peak growth much sooner on nutrient-rich than on nutrient-poor sites.

In general, losses in wood production are proportional to foliage losses. However, the relation is not linear over the whole range of defoliation intensities because plants can compensate for low-level defoliations of less than 40% with little if any loss in production. There are suggestions that such defoliations can actually stimulate vegetative and reproductive growth of plants. Production losses may be proportional to foliage losses when defoliation exceeds 40%. However, this relation is confounded by such factors as cumulative defoliation effects, general health of the plants, and weather.

To evaluate the qualitative and quantitative nature of interactions between overstory trees and insects, the authors simulated and then

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compared annual biomass production in a **Populus tremuloides** forest with and without forest tent caterpillars, **Malacosoma disstria**. In this example, defoliations reduced wood growth by 14 to 92%. Leaf production increased temporarily because fully defoliated trees refoliated: the biomass of the second crop of leaves was about two-thirds that of a normal first crop.

The authors' model showed that forest tent caterpillars affected forest production most severely in the fifth and sixth years, after which the effect gradually diminished to become nearly negligible. Following defoliation, tree diameters and heights were smaller in the grazed stand than in the ungrazed stand. However, there is evidence to suggest that aspen stands defoliated for 2 or 3 years may actually show larger height growth and slightly more diameter growth than that shown before defoliation. Wood production may increase after severe defoliations because the circulation of nitrogen, phosphorus, and potassium is enhanced or the distribution of light and moisture is more equitable. Moderate to severe defoliations can increase normal nitrogen, phosphorus, and potassium contributions in the litter fall by 20 to 200%. This occurs because litter fall is not only greater but also richer than normal due to the exceptionally high concentrations of nutrients in dead insect bodies, insect excrement, and wasted food parts. This enhances the soil organisms and one result can be increased plant growth.

The impact of tree defoliations on total primary production depends in part on the kind and quantity of understory revegetation. Where there is little or no understory vegetation, the response to overstory defoliations will be small. Moreover, some plant species will respond more than others to overstory changes. Typically, understory trees and saplings respond with increased growth when overstory trees are defoliated. In general, one can assume that the underatory vegetation, if it is not also defoliated, will reduce the differences in primary production between forests with defoliated and nondefoliated understories.

There is circumstantial evidence that insects can detect and respond to subtle changes in host quality brought about by such factors as aging, nutrient deficiencies, and moisture stresses. This has led foresters and insect ecologists to conclude that insect population growth is inversely related to host plant vigor. For example, many reports indicate that massive insect outbreaks typically begin in middle-aged to mature forests, which are in the waning end of their productivity cycle. Localized outbreaks seem to occur in forests of all ages, but are typically associated with the least vigorous, slowest growing plants. Furthermore, outbreaks are often preceded by extrinsic stresses to plant systems, such as pollution, drought, or excessive moisture. For example, Ives (1974) concluded that several summers of warm, dry weather appear to cause outbreaks of the spruce budworm **Choristoneura fumiferana** in

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mature forests. Others have reported that outbreaks of numerous defoliators occur first and most commonly on ridgetops and at higher elevations, where soil moisture depletions and other climatic stresses may be most severe and more frequent.

Both grazers and saprophagous heterotrophs degrade plant materials into smaller, simpler substances. In so doing, they enhance the circulation of nutrients needed for plant growth. However, there are differences among ecosystems in the fraction of plant biomass consumed directly by these two trophic groups. In most forest ecosystems, for example, grazers consume only about 5 to 10% of the above-ground biomass, and the remainder goes directly to saprophages.

In summary, insect grazers may have direct effects such as changes in: 1) the mobilization and utilization of stored reserves and nutrients trapped in sinks; 2) the efficiency of photosynthetic processes; 3) the initiation and differentiation of bud primordia; and 4) the metabolism and growth of cells. Besides these direct effects, grazers interact indirectly by altering the abiotic flux to both grazed and nongrazed plants. For example, grazers can change the vertical distribution of biomass production in ecosystems. There are documented instances where the understory vegetation produced enough biomass to compensate for the production lost by the severely defoliated overstory trees. Therefore, the total importance of grazers in the processes of primary production and nutrient cycling has probably been underrated in most terrestrial ecosystems because it has been assumed, until recently, that their influence is limited primarily to reduction in leaf surface area and degradation of consumed plant material, which typically is a small share of the annual primary production. Although very important, saprophages are more passive than grazers in their regulative effects on nutrient cycling and primary production. Grazers interact with autotrophs more directly and through more channels than do decomposers. Insect grazers have the effect of ensuring consistent and optimal output of plant production over the long term for a particular site. Their activities seem to vary inversely with the vigor and productivity of the system. This inverse relation is probably a consequence of the long history of co-evolution between plant systems and their consumers.

1. MCLEAN A. and J.H.G. SMITH

2. 1973

3. Effects of climate on forage yields and tree-ring widths in British Columbia.

4. Journal of Range Management 26:416-419

5. a. Canada; Index map NN-10; British Columbia

   b. Nil

   c. Climatic variation (temporal)

6. This study examined the possible use of trees to indicate long-term influences of climate and to estimate forage production for past years. The authors examined whether or not tree growth was correlated with range herbage production, even though it was known that growth of grasses, forbs, and shrubs will respond differently than trees do to variations in climate.

For the forested rangeland sites it was not possible to find any consistent relationships between the variations in forage yield or tree growth and the records of monthly temperature or precipitation from the weather stations closest to each locality sampled. None of the yields were consistently related to variations in climate. Yields increased with elevation and were highly variable from year to year and among sites. Inspection of the tabulated yields suggested, however, that excessively dry springs and unusually low annual precipitation resulted in low yields. Dry summer months (June, July, and August) were associated with superior yields provided the past year had been wet.

Forage yields on open rangelands (1954 to 1969), although only moderately associated with individual values for seasonal average temperature or total precipitation, could be estimated very well by all weather variables describing a 15 month period. The 190 observations of yield from 16 open rangeland locations averaged 610 kg/ha, oven dry, with a minumum of 94 kg/ha in 1967 and a maximum of 690 kg/ha in 1965. Expressed as percentages of 1963 yields, annual forage weights averaged 116% and ranged from 53 to 214%.

The authors suggested that because both forage and wood yields are strongly influenced by climate, the possibility of extending records of annual forage yields back in time by use of tree-ring analysis still remains worthy of study. They recommended that investigations be made at comprehensively analysed sites to determine local effects of soil and climate by direct measurement of their effects on both growth and yield of forage and wood.

1. MEENTEMEYER, Vernon, Elgene O. BOX and Richard THOMPSON

2. 1982

3. World patterns and amounts of terrestrial plant litter production.

4. Bioscience 32:125-128

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb), Climate/growth (direct relationships, latitude)

6. This article describes computer models that relate leaf litter production and total litter production to appropriate climate variables over the full range of terrestrial climates found on earth. Climatic variables used in the model were: mean monthly values of temperature and precipitation; annual values of precipitation; potential evapotranspiration and actual evapotranspiration; the fraction of actual evapotranspiration over potential evapotranspiration; and photosynthetically active radiation. These variables were selected because they include the availability of thermal energy, water and light. Actual evapotranspiration which combines the availability of heat and soil water in one variable has been found to be an especially good predictor of primary production, litter decomposition rates and various other plant processes. The special value of evapotranspiration as a predictor relates to the fact that this parameter responds to all possible combinations of energy and moisture availability to an ecosystem.

Reviewing other research in this area, the authors noted that there have been few attempts to determine with precision the geographic patterns of litterfall or to relate litterfall quantitatively to climatic variables. Some earlier research has determined that light availability during the growing season is strongly related to forest litter production. Forest litter production has also been related to latitude and qualitatively to temperature, precipitation, and solar radiation during the growing season. In general, litter production does seem to be controlled by climate as much as by edaphic factors.

Correlations of net primary production with climate have produced some good correlation-regression models. Previous studies have calculated the regression between net primary production and actual annual water loss by evapotranspiration, and have correlated measured values of net and gross primary production with various environmental variables. These results have been applied to large environmental data bases to produce predictive world maps and have also been quantified.

The authors' simple linear regression-correlation analysis revealed that annual leaf litterfall correlates very well with annual actual

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Meentemeyer, V., E.O. Box and R. Thompson. 1982. Continued

evapotranspiration ($r = 0.89$) and slightly less well with latitude ($r = 0.83$), but only moderately well with annual potential evapotranspiration ($r = 0.64$). The maps generated by their model clearly reflected the high production in wet tropical areas and low production in arctic and desert areas. In their model, litter production was quantitatively tied to climate. Thus, if climate were to change, or if a scenario of climatic changes were devised, it would be possible to predict new patterns of litter production that could result from climatic change.

The predictive equations were:

Total litterfall ($g/m^2/yr$) = 1.0066 (Actual annual evapotranspiration, cm) - 183.92

Total litterfall ($g/m^2/yr$) = 433.6 - 8.185 (Latitude) + 0.5309 (Actual annual evapotranspiration)

Total litterfall ($g/m^2/yr$) = 888.59 - 11.35 (Latitude) - 3.63 (Photosynthetically active radiation) + 0.43 (Actual annual evapotranspiration)

The world totals for annual leaf and litter production predicted and quantified by this model were 35.1×10^9 t and 54.8×10^9 t, respectively. The figure of 54.8×10^9 t for total litter is almost exactly half the estimates of total annual net primary production of 107 to 128×10^9 t for all land areas obtained by other computer models. Although litter appears to represent a major fraction of total net primary production, each year's litter production, even before decompositional losses, represents a very small fraction of the earth's total pool of organic carbon. This pool has been estimated to be $1,457 \times 10^9$ t of carbon or about $2,768 \times 10^9$ t of dry matter. The 35.1×10^9 t estimated for annual terrestrial leaf litter production is 64% of the estimate of total terrestrial litter production. This suggests that there are some regions where the leaf to total litter ratio deviates from the general 70% relationship proposed earlier.

1. MIKOLA, Peitsa

2. 1956

3. Tree-ring research in Finland.

4. Tree-Ring Bulletin 21:16-20

5. a. Finland

   b. Scots pine, Norway spruce

   c. Climate/growth (direct relationships, indirect influences, latitude), climatic change (dendrochronology), Treeline studies (growth, climate)

6. Previous studies in Finland had indicated that tree height and diameter growth are different in their relation to climatic factors. Annual height growth depends on the temperature of the late summer of the preceding year. The width of the annual ring, on the other hand, is dependent on the spring temperature of the current year. In Finland there appears to be an 11-year cycle and the maxima and minima of diameter growth coincide with the maxima and minima of sunspot cycles.

Data from studies near the northern Scandinavia treeline indicated that diameter growth of trees depends closely on the temperature of the growing season. A clear correlation exists between the diameter growth of pine and the July temperature. Towards the south, the correlation weakens. The author confirmed that diameter growth of pine depends mainly on temperature of the late season (July) while that of spruce is more dependent on temperature of early summer (June). Variations in the width of early wood are much smaller than in the width of late wood. The late wood is broader, both absolutely and relatively, if growth commences relatively earlier in spring and if temperatures are relatively higher in middle and late summer.

In Finland no correlation has been found between precipitation and diameter growth of trees. In central Europe, however, growth of trees is evidently proportional to precipitation, and the author suggests that moisture may exert some influence in Finland, too, but its significance is hard to ascertain because rainfall and temperature of the growing season are usually more or less inversely proportional. It is noticeable that very dry summers have been unfavourable to tree growth on the driest sites, just as very rainy summers are on wet peatlands. In general, however, growth variations are rather uniform, independently of site.

Tree-ring studies of the northern treeline area revealed that variation is largest where growth is determined mainly by one varying factor, as by temperature on the northern treeline or by moisture in the transitional zones between forest and steppe. When going from north to south, the

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variation gets smaller. The author also noted that climatic variations in pine growth at the northern treeline are often accentuated by frost injuries. A prolonged growth depression, such as occurred in northern Scandinavia in 1903-1911, may be due to one single year of heavy frosts. Corresponding depression in spruce growth does not exist, and therefore the growth improvement of spruce in the period from 1911 to 1930 is not so steep as that of pine. The author's tree-ring analyses also revealed growth depressions, both in pine and in spruce, that probably result from damage caused by insects or fungi.

1. MIKOLA, Peitsa

2. 1962

3. Temperature and tree growth near the northern timber line.

4. IN: Theodore T. Kozlowski, Editor, Tree growth. The Ronald Press Company, New York, p. 265-274

5. a. Finland, Sweden

   b. Norway spruce, Scots pine

   c. Climate/growth (direct relationships, latitude), Climate change (dendrochronology), Growing season (length), Treeline studies (growth, climate)

6. The decisive climatic factor affecting radial growth of trees under northern conditions in Finland is temperature of the growing season. The dominance of temperature masks other possible climatic controls over growth. The effect of deficient rainfall can be traced only in exceptionally dry summers on the driest sites, and the harmful effect of excessive moisture is evident only on wet peatlands in rainy summers. Further south, for example in Denmark, rainfall of the growing season has proved to be the most important climatic factor affecting tree growth.

The influence of summer temperature upon tree growth increases from south to north and is most accentuated at the northern treeline. Annual variation of radial growth likewise increases towards the north. The latter is explained by the fact that the limiting growth factor, summer temperature, is less favourable in the north, and at northern treeline the temperature fluctuates from year to year on both sides of a critical limit; as a result annual variation of ring width reaches its maximum at northern treeline.

When annual radial growth of Scots pine was compared with different thermal indices the best correlation was found between growth and July temperature. This correlation was quite evident even in southern Finland, but was better in the northern part of the country. There are two reasons for the better correlation in the north. First, further south there are other climatic factors that exert some influence and modify the effect of temperature; in the north the temperature effect is more dominant. Second, the growing season is longer in the south and weather conditions in June and August may also affect growth, although less than the July weather; in contrast, near the northern treeline the short growing season coincides approximately with the month of July.

Both the beginning and the length of growing season vary from year to year. The dates of onset of radial growth may differ by as much as a month and total length of the growing season will also vary. Under conditions where temperature is the limiting growth factor, temperature

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aggregate or thermal sum during the growing season is probably decisive, and therefore the maximum temperatures may be more important than mean temperature of a fixed period. In northern Sweden, a very high correlation between annual radial growth of pine and number of days when the maximum temperature exceeds 19°C has been found.

When the earlywood and latewood constituents of annual rings were compared with climatic factors an interesting relationship was noted. If growth starts earlier than usual in spring, there is a broader latewood ring and a higher percentage of latewood in the whole ring. In annual rings of pine, width of latewood varies relatively more than that of earlywood. It was concluded that, in southern Finland at least, length of the period of earlywood formation is almost constant from year to year. However, since radial growth ceases almost simultaneously every year around the middle of August, the amount of latewood is proportional to length of growing season. In pine, variation of the July temperature also has a more distinct effect on width of latewood than it does on earlywood. Growth of earlywood takes place partly at the expense of nutrient reserves and is therefore also dependent on weather conditions of early spring and even the preceding summer. Growth of latewood, on the other hand, is to a greater extent determined by prevailing temperature conditions during the current growing season.

Radial growth of Norway spruce also depends mainly on temperature of the growing season. There are, however, some differences from the reaction of pine. The most decisive period for spruce growth is a little earlier than for pine. If ring width and monthly mean temperatures are compared, then the highest correlation for pine growth is obtained with July temperature, whereas for spruce growth highest correlation usually is with June temperature. In annual rings of spruce, latewood width varies very little from year to year, and variation of the whole ring width is mainly due to different amounts of earlywood. There is a relatively good correlation between the width of earlywood of spruce and mean June temperature.

The difference between Scots pine and Norway spruce in their relation to summer temperature is clearly visible if climatic conditions are studied in summers when one species has grown better and the other less well than in the preceding year. If spruce has grown better, for instance, and the pine less well, then the early summer has usually been warmer and the late summer cooler than in the preceding year, and vice versa.

Temperature of the growing season also has some influence on radial growth of the following years. This lag effect is most pronounced near northern treeline, where the poorest growth often occurs in the year following a climatically unfavourable year. There may be several reasons for such a lag effect. For example, temperature may influence the vitality and nutrient reserves of the tree. Temperature also has an influence on the green surface area of the tree, which in turn affects

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other growth phenomena. The green surface area depends on both the length and number of needles formed each year.

Annual height growth of Scots pine is determined mainly by temperature of the preceding summer. Good correlation exists between length of the terminal shoot and the July and August temperatures of the preceding year. This is explained by the fact that the number of needles on a shoot is predetermined in the bud, which is formed in the preceding summer, and the length of shoot depends mainly on the number of needles it bears. Length of needles depends on climatic conditions prevailing during their growth, with temperature being the most important factor.

The northern treeline is determined by temperature and coincides with the isotherm of 10° C of the warmest month. Temperature is the primary limiting factor for tree reproduction. Ripening of Scots pine seed requires a mean temperature of 10.5° C during the four summer months. Such warm summers are exceptional at northern treeline, occurring about once every hundred years. Vegetative growth of Scots pine has a minimum requirement of about 8.5° C for the four summer months. Annual and long-term variations in tree growth are extremely pronounced at northern treeline where summer temperatures fluctuate near such threshold values.

Dendrological indices from six localities north of 68°N in Finland have a uniform pattern of growth variation. All sites show a deep growth depression during the years 1902 to 1911, and then a continuous increase until the 1930's. The more northern localities show the greatest responsiveness to climatic changes. In the two northernmost localities the dendrological index from 1902 to 1911 was 60 to 80% below the normal level, and during the favourable period of the 1930's up to 100% above the normal level. There are several possible reasons for the pronounced depression of growth between 1902 and 1911. There were several cool summers during this period, and a prolonged lag effect may have occurred. There are also accounts of great frost damage in pine stands at northern treeline in 1902. Both thermal conditions and tree growth reached a peak in the late 1930's. Thereafter temperature declined in northern Finland and forest growth followed the same trend.

1. MIKOLA, Paitsa

2. 1970

3. Forests and forestry in subarctic regions.

4. IN: Ecology of the Subarctic Regions. Proceedings of the Helsinki Symposium, Paris, UNESCO. p. 295-302

5. a. Finland, Norway, Sweden

   b. Birch, Scots pine

   c. Climate/growth (latitude), Climatic variation (temporal, temperature), Growing season (length)

6. The subarctic vegetation zone is defined as a transition between the boreal coniferous belt and the treeless arctic tundra. This transitional nature is generally referred to as "forest tundra". Thus, the northern part of the subarctic zone consists mainly of tundra, with scattered trees or small stands in protected localities. The proportion of wooded areas increases towards the south, treeless areas diminish, and tree stands become denser and higher.

On a circumpolar scale, it has been estimated that the total area of the boreal forests is 9.9 million km^2. One-third to one-fourth of this area (2.5 to 3 million km^2) might be classified as subarctic forests. Although the timber volume and annual growth per unit area are low in subarctic forests, owing to the tremendous areas involved, they comprise considerable timber resources and potential wood-producing capacity.

According to the Finnish national forest inventory in the drainage area sloping to the Arctic Ocean, which approximately corresponds to the subarctic part of the Finnish territory, the average standing timber volume (including bark) on productive forest land, which is mainly pine forest, is 53 m^3/ha. In birch forests of the forest tundra zone it averages 15 m^3/ha. The annual growth has been estimated at 0.8 and 0.4 m^3/ha for these two zones respectively. In Finnmarken of Norway the standing volume has been estimated at 18 m^3/ha in pine forests, and only 8 to 11 m^3/ha in the subarctic birch forests.

The ecological factors that restrict the growth and even the existence of subarctic forests are mainly climatic. The short duration and low temperature of the growing season are the primary factors resulting in slow growth and small size of trees. Moisture is usually sufficient, and in geologically young soils the nutrient status is generally satisfactory. The paramount importance of temperature has been shown by several studies; a close correlation exists between the width of the annual ring and the summer temperature.

To mature, the tree seed needs a certain amount of heat, an amount which is greater than that necessary merely to support life and vegetative

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growth. In an average year the amount of heat is insufficient for tree seed to mature in subarctic areas; thus, reproduction by seed is possible only after summers that are warmer than average. It has been estimated that at the outermost treeline in northern Scandinavia reproduction of pine occurs only once in a century, whereas on the southern edge of the subarctic zone climatic conditions would permit seed maturation once in ten years, on the average. More recent studies have indicated that reproduction years at the northern treeline are not quite so concentrated in certain periods of unfavourable years, and between these periods several decades may elapse without any regeneration. Since the maturing of seed depends only on summer temperatures, the continuous existence of forests in the northern treeline region is determined by how often summers recur which are sufficiently warm for seed to reach maturity. Consequently, even slight climatic fluctuations may cause an advance or retreat of the forest limit.

Meteorological data indicate that for at least a hundred years (1850 to 1950) the northern European climate has been growing warmer, and consequences of this trend are visible in both the fauna and vegetation. Thus, since 1920 pine seed has matured in several years up to the northernmost treeline and at the present time thriving young seedlings are common in the Scandinavian forest tundra. Natural reproduction of pine forests has also proved successful in northern Norway. Recent investigations suggest that the forest limit has advanced in the last few decades. This assumption is also supported by the fact that the trees of the northernmost pine stand of the world (Staburdalen, Norway, 70 40 N) are thriving and there are numerous young seedlings.

1. MIKOLA, Pietsa

2. 1971

3. Reflexion of climatic fluctuation in the forestry practices of northern Finland.

4. Reports of the Kevo Subarctic Research Station 8:116-121

5. a. Finland

   b. Scots pine

   c. Climate (temperature), Climate/growth (direct relationships, latitude), Climatic variation (regional, temporal, temperature), Growing season (degree day totals), Treeline studies (climate)

6. An amelioration of summer temperatures was apparent in northern Finland from the late 1800's to the 1930's. Near the northern treeline, successful pine regeneration occurred where there had been an almost total absence of reproduction from the mid-1800's to the late 1800's. Abundant natural reproduction of pine near the treeline was also observed elsewhere in northern Scandinavia. Natural reproduction which had taken place in several years during the 1920's and 1930's was attributed to an improved climate.

Summer temperatures have shown a descending trend since the 1930's. The mean temperatures for the four summer months at Sodankylä and Inari was 0.8° C lower in the 1960's. The mean temperatures of July, which is the most decisive month for vegetative growth of pine at northern treeline, had decreased by 1.6° C and 1.8° C in Sodankylä and Inari, respectively.

The mean temperatures (0° C) of July and for June-September and thermal sums of the growing season at Sodankylä and Inari were as follows:

	Sodankylä			Inari		
	Mean July temp.	Mean June-Sept. temp.	Thermal sum*	Mean July temp.	Mean June-Sept. temp.	Thermal sum
1911-20	15.3	10.7	(781)	14.1	10.0	(690)
1921-30	14.9	11.0	808	13.7	10.1	(703)
1931-40	15.0	11.3	861	14.2	10.6	(768)
1941-50	14.8	11.1	818	13.7	10.3	(729)
1951-60	14.4	10.8	809	13.3	10.2	(716)
1961-70	13.4	10.5	772	12.4	9.8	(664)

* Thermal sum is the summation of daily mean temperature (° C) minus 5°, expressed as day-degrees; the thermal sums in brackets have been calculated from the June-September mean temperatures according to the formula: $y = 130x - 610$, where y = thermal sum and x = mean temperature of June-September.

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The thermal sum is considered to be a better climatic indicator than the mean temperature from June to September. However, a close correlation prevails between the thermal sum and the mean temperature from June to September. Since mean temperatures are more readily obtained, the author chose to use this form of temperature data to illustrate the thermal conditions of the growing seasons.

Several studies have consistently shown that the maturation of pine seed depends mainly on summer temperature. Early studies reported that no viable seed was obtained unless the mean temperature of the four summer months exceeds 10.5° C, and a mean temperature of at least 11.5° C is required for a seed crop of good quality. At Karasjok in northern Norway, the mean temperature from June to September exceeded 10.5° C only three times in the period 1890 to 1919, whereas in the following 30-yr period, 1920 to 1949, the same temperature limit was exceeded 14 times.

The failure of forest regeneration programs in Finland is believed to be due to a less favourable climate. A steep rise in the percentage of failures was evident in more northern regions of Finland. Still higher failure percentages were found at northern treeline, probably due to three exceptionally cold summers, 1962, 1965 and 1968. The summers of 1962 and 1968 were the coldest since regular meteorological observations were started at Sodankylä and Inari.

Based on predictions by Sirén, the author indicated that the descending trend of temperature is likely to continue and no improvement can be expected until after the turn of the century. This forecast must be seriously considered in the future planning of forest management. Forestry is not the only field in which favourable experiences in the warm period of the 1930's encouraged overoptimistic expectations in Finland. Agriculture has likewise suffered losses, which can be attributed to extension of the cultivation of various crops further north than average climatic conditions would have permitted.

1. MILLER, Philip C., (Editor)

2. 1981

3. Carbon balance in northern ecosystems and the potential effect of carbon dioxide induced climatic change.

4. U.S. Department of Energy, Office of Environment, Washington, D.C. Carbon Dioxide Effects Research and Assessment Program, 015, CONF-8003118. 109 p.

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels)

6. The 24 participants of a workshop held in San Diego on 7-9 March 1980 based their discussions on the possibility that ecosystems north of about 60° N may become important in the global carbon balance if there is increased warming due to carbon dioxide buildup because of their large reserves of dead organic carbon and their high sensitivity to climatic change. Given the potential significance of these ecosystems, the objectives were to estimate their current carbon balance as precisely as possible, to improve estimates of the future carbon balance if world climate changes, and to assess the range of certainty associated with these changes.

The total ice-free land area in northern ecosystems is 17.4×10^6 km^2, of which 5.7×10^6 km^2 is in the arctic, 10.6×10^6 km^2 in taiga, and 1.1×10^6 km^2 in peatlands. The total standing crop of carbon is 232 BmT (1 BmT = 10^9 metric tonnes), including 74 BmT in the circumpolar arctic and 158 BmT in the taiga. Carbon in northern peatlands and bogs may add an additional 167 BmT. The estimate of net primary production is about 0.5 BmT C/yr in arctic and 2.3 BmT C/yr in the taiga. Current rates of carbon accumulation in northern ecosystems are about 0.03 to 0.3 BmT/yr; rates have been 2 to 3 times higher during past warm periods analogous to those expected in the mid-21st century.

The participants' estimate of the areal extent of taiga is similar to previous estimates but the estimate of the carbon standing crop in taiga is 70 to 85% of previous estimates. The standing crop of carbon in world taiga is lower than previous estimates but is within the range recorded elsewhere. The estimated standing crop of carbon in dead organic matter is also lower than previous estimates for both tundra and taiga, about half the estimated values for northern ecosystems of Ajtay et al. (1979). The agreement between estimates gives a level of uncertainty of about 20% of the mean total areal extents, 30 to 40% of the mean for biomass carbon, but 50 to 100% of the mean for dead organic carbon. Values for the standing crops and areal extents of the ecosystem types for the U.S.S.R. are particularly uncertain and are important to reduce the range of uncertainty associated with the mean estimates.

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Based on the information currently available, it is unclear whether northern ecosystems will provide negative or positive feedback in the global carbon cycle with the predicted increase in atmospheric carbon dioxide, although most evidence indicates a negative feedback role. The current distribution of organic carbon and temperature of different vegetation types and analyses of paleoclimates and pollen stratigraphies indicate that with increasing temperature the carbon content of the arctic should increase while that of the taiga should remain about the same. The natural pattern of past climatic fluctuations indicates a re-occurrence of a warm period at about year 2030 which may accentuate the effect of carbon dioxide induced warming. Process studies indicate that with increasing temperature respiration will increase more than photosynthesis, while decomposition and mineralization may be temperature insensitive. The effect should be increasing carbon accumulation in the ecosystem.

The summary of present knowledge in these workshop proceedings is presented as six separate chapters, each written by four or more co-authors, on the following subjects: current areal extents and carbon contents of northern ecosystem types; current carbon accumulation rates in northern ecosystems; future carbon accumulation rates in northern ecosystems based on current geographic patterns of temperature and carbon content; future vegetation patterns and carbon accumulation rates based on past vegetation patterns; future carbon accumulation rates based on current knowledge of production and decomposition processes; and implications of carbon dioxide induced climatic change on animal ecology and socioecological consequences in northern ecosystems. The proceedings also outline the structure of a northern ecosystem carbon simulator which was developed for the workshop to evaluate the important carbon compartments and to allow the importance of various compartments and the variables regulating their gain and loss to be seen in relation to each other. The purposes were to clarify the magnitudes of the processes of carbon flux and the factors controlling carbon flux, areal extent, and standing crop of dominant vegetation types, and to ascertain the effect of current uncertainty associated with these variables on predictions of the future carbon balance in northern ecosystems from 1970 to 2030.

Research needed to determine the effect of increased carbon dioxide on northern ecosystems falls into four major categories: 1) estimates of the current amounts of carbon in the arctic and taiga should be refined by mapping areal extents of organic matter quantity and quality; 2) process studies, integrated by modeling and validated at research sites which sample the circumpolar arctic and taiga, should be carried out to clarify the major controls and net annual carbon flux and the areal extents of the important vegetation types; 3) historical studies are needed to clarify past climatic conditions under which major accumulations of peat occurred, natural oscillations and current trends in climate, and the rapidity of change in vegetation and soil organic matter; and 4) studies should be undertaken on aspects of animal and socioeconomic ecology which may be politically important with carbon dioxide induced climatic change.

1. MILLER, Wayne S. and Allan N. AUCLAIR

2. 1974

3. Factor analytic models of bioclimate for Canadian forest regions.

4. Canadian Journal of Forest Research 4:536-548

5. a. Canada; Index maps (all in boreal section); all boreal forest sections in Canada

   b. Nil

   c. Climate/growth (direct relationships)

6. To interpret the relationship of climate and vegetation in an objective fashion, it is desirable to reduce the number of variables to a manageable few. One must either consider the variables separately and establish climate-vegetation correlations at this level, or else generate a synthetic description that represents a complex of variables. The latter approach is made possible by principal components analysis (PCA). Although PCA has proved useful for bioclimatic studies on a restricted geographical level, a multivariate analysis of vegetation-climate relations for a broad spectrum of forest regions and prevailing air-mass types is not available. This study attempted to develop such a model for forest regions of Canada.

Climate attributes examined by the authors were the same ones used by Rowe (1972) for 111 Canadian meteorological stations. The climatic parameters originally selected by Rowe as part of his description of forest regions in Canada included:

Mean annual temperature (°F)
January average daily minimum temperature (°F)
July average daily minimum temperature (°F)
Start of growing season: average date mean temperature rises to 42°F
End of growing season: average date mean temperature falls to 42°F
Length of growing season: average number of days mean temperature is equal to or less than 42°F
Mean temperature May to September (°F)
Mean rainfall May to September (°F)
Mean annual precipitation (inches)
Annual potential evapotranspiration (inches)

The authors used annual summaries of meteorological variables, whereas other investigators have favored monthly summaries or else growing-season data when analysing climate-forest relations. The models developed by the authors gave a separation of major forest regions. The first component distinguished Boreal from Coast, Acadian, and to a lesser degree Great Lakes - St. Lawrence forest regions. The second component differentiated Columbia, Grassland, and Montane regions from the Boreal and Coast forest regions. In addition to this generalized model, the analysis was able to identify the mean summer position of the arctic polar front and a regional low pressure locus over central Alberta.

1. MITCHELL, Val L.

2. 1967

3. An investigation of certain aspects of tree growth rates in relation to climate in the central Canadian boreal forest.

4. University of Wisconsin, Department of Meteorology, Madison, Wisconsin. Technical Report No. 33, 62 p

5. a. Canada; Index maps (all in Mackenzie, Keewatin, Manitoba, Ontario and Saskatchewan); All boreal forest sections in Northwest Territories, Manitoba, Ontario and Saskatchewan

   b. Black spruce, white spruce

   c. Climate (precipitation, temperature), Climate/growth (direct relationships, indirect influences, microclimate, latitude), Climatic variation (regional, temperature), Growing season (length), Treeline studies (growth, climate)

6. The Department of Meteorology of the University of Wisconsin has conducted extensive climatological and botanical studies in central and northern Canada. As part of these studies, several thousand core samples of tree rings were collected in the boreal region from Yellowknife southeast to Kapuskasing.

Once each ring series has been standardized by being reduced to an index series, it is possible to compare one series with another and to investigate the relationship between tree growth and climate. There are factors other than climate that affect tree growth, many of which are limited in that they affect only one or a few trees in a stand. One of the most notable of these is microclimate. The extensive modification of the microclimate by local features is fairly well documented in both the meteorological and botanical literature. These microclimatic effects can be quite restricted in areal extent and thereby affect a small number of trees in a stand. Nonuniformity of soil drainage and different histories of competition and catastrophe can also cause the growth pattern of one tree to differ from that of another tree not far away.

Several methods have been used to compare climate with tree growth. Most of them involve the use of climatic parameters for one or more months rather than yearly values. This is a reasonable approach since trees outside the tropics do not grow throughout the entire year, and therefore cannot be expected to respond equally to the climate of each portion of the year.

Tree growth is not uniform throughout the central boreal forest. This should be expected since there are gradients of many climatic parameters across this region. Gradients of meteorological parameters are usually normal to fronts associated with air masses. Since tree growth variance

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is largely controlled by climate it can be expected that gradients of tree growth also run normal to the mean arctic front position, and therefore the treeline. Studies of plant communities in the study region confirm this relationship.

The minimum growth rate for black spruce decreases only slightly as the distance to treeline decreases. The author calculated maximum and minimum growth lines which represent the maximum and minimum growth rates possible for most of the tree species in the boreal forest. These growth lines converge as they approach treeline and intersect at a point beyond treeline. Beyond this point, climatic conditions are such that the maximum growth possible is less than the necessary minimum growth rate. The intersection gives, essentially, a theoretical treeline. Though the actual treeline occurs at the mean summer position of the arctic front, the position of this front at any given time may deviate from the mean. When the front is south of its mean position, climatic conditions near the theoretical treeline are more severe than normal, thus inhibiting tree growth there. The author noted that the theoretical treeline crossed Dubawnt Lake and coincided very well with the actual limit of trees in that area.

It is believed that white spruce differs from black spruce in its response to climate. In the southern portion of their range, their growth rates are quite similar. However, as the climate becomes more severe, the average growth of black spruce decreases more rapidly than that of white spruce. This may be due to differences in sites occupied by the two species, since black spruce is found on many sites while white spruce is generally restricted to the better sites. There may also be factors involved that are related to biological differences between the two species.

The length of the growing season is a function of both species and climate. The most probable period of growth for black spruce is from sometime in May to August or possibly September. Another factor that must be considered is that the response of cambial growth to specific climatic parameters is not clearly understood for black spruce or any other species in the study region. In most of the trees studied, the previous year's growth is an important factor in determining the current year's growth. The mechanism for this relationship apparently lies in the increased amount of food stored by the tree in years of good growth. This food is utilized in the next year's growth, thereby permitting a wider ring than would otherwise occur. This is a very common factor in tree growth and it is reflected in the high first order serial correlations that are usually found in trees from other than limiting sites.

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The author described the following tree growth responses based on various combinations of weather conditions:

Example 1 - Growth is much above normal probably due to an early start in spring and a cool summer with no moisture stress on the tree; July is cold but is apparently still above the minimum temperature required for growth;

Example 2 - Growth is much above normal even though the start of growth in spring is retarded by low temperatures; however, temperature conditions in July and moisture conditions in July and August are such as to promote good growth;

Example 3 - May is cool and the high precipitation in June results in low amounts of solar energy available to the tree; if the tree experiences moisture stress in July due to low precipitation and in August due to high temperature, the combination of a late spring and moisture stress in summer results in below normal growth;

Example 4 - Below normal growth is the result of the entire growing season being cool to cold, thus limiting growth;

Example 5 - April, May, and June are nearly normal; July is cool and wet but August is very dry; in this case, growth is somewhat above normal because of sufficient moisture in July; however, growth is probably terminated by moisture stress in August;

Example 6 - A combination of a very dry April and moisture stress in June and August results in below normal growth; a warm, wet July does not completely compensate for the dry months.

The results of this study show that isolines of tree growth rate are parallel to treeline. Site characteristics play an important role in tree growth throughout the boreal forest region. The black spruce data indicate that this species grows on two types of sites in some of the areas. One group of sites results in fast growth and the other in very slow growth.

In summary, the length of the growing season is important in tree growth and can be increased by either a warm period in spring or by a moist period in late summer. Very low temperatures in summer can retard growth as can moisture stress. Any one of these factors can be offset by some other factor or combination of factors. The author observed that each tree responds to its own local microclimate, which apparently differs somewhat from the microclimate of each of the other trees. Site differences play an increasingly important role in tree survival as treeline is approached. The nonsimilarity between trees from the central and southern boreal forest indicates that local site factors are also very important even in the middle parts of the boreal forest.

1. MITCHELL, Val L.

2. 1973

3. A theoretical tree line in central Canada.

4. Annals of the Association of American Geographers 63(3):296-301

5. a. Canada; Index maps NP-13/14, NO-15, NO-16, NN-16, NN-17; District of Keewatin, District of Mackenzie, Manitoba, Ontario; B.32

   b. Black spruce

   c. Treeline studies (growth, climate)

6. The central boreal forest of Canada presents an opportunity to study the broad influence of climate on tree growth because the region is free from any major topographic differences, and its vegetation is relatively homogeneous.

Bryson (1966) has shown that the northern limit of the boreal forest in Canada coincides with the mean summer position of the arctic front. Gradients of meteorological parameters are usually perpendicular to fronts. Since tree growth variance is largely related to climate, gradients of tree growth also can be expected to run normal to the mean arctic front position and to treeline.

The mean ring width added to a tree during a given time is not comparable with the mean ring width of another tree for the same period, unless the two trees are approximately the same age, because the maximum diameter growth of a tree is in or just below the active crown. As the height of the tree increases and the base of the crown gets higher above the ground, the region of maximum diameter growth migrates upward. To avoid the problem of noncomparability of growth data from trees of different ages, the ring width for the one hundredth year of the derived growth curve for each tree was used by the author as a growth index. In all cases but one, the growth index was linearly related to the distance from the forest-tundra boundary or treeline.

Based on data from black spruce, the author concluded that tree growth in central Canada decreases linearly toward the forest-tundra boundary. This sharp ecotone coincides with the mean summer position of the arctic front. Growing conditions decline steadily northward and finally become so adverse that trees can survive only where the microclimate is favourable. The concept of a theoretical treeline, north of which tree survival is not possible, is consistent with the observed distribution of black spruce in central Canada and can be explained by the movements of the arctic front. Although small sample size precluded use of data on white spruce, the author recommended that this study be extended to include both white spruce and jack pine.

1. MOORE, T.R. and E. VERSPOOR

2. 1973

3. Aboveground biomass of black spruce stands in subarctic Quebec.

4. Canadian Journal of Forest Research 3:596-598

5. a. Canada; Index map NO-19; Quebec; B.13a

   b. Black spruce

   c. Biomass (tree)

6. There is a dearth of biomass data for forested subarctic areas, and this note reports black spruce biomass characteristics for six stands from measurements in the Cambrien Lake area of northern Quebec (56 30 N, 69 15 W), located in the northeastern transition section of the Boreal Forest Region. Within the area, black spruce occurs in two vegetation associations: as scattered individuals and clumps in spruce-lichen woodlands, and at a higher density in spruce-moss forests.

The authors developed regressions of weight against diameter breast height (d.b.h.) or height of black spruce as summarized below:

	Height (m)	Regression equation*	Standard error	r^2
Spruce-lichen woodland	over 1.5	$\log_{10} y = 0.141 + 1.544 \log_{10} x$	0.178	0.831
	under 1.5	$y = -1.556 + 0.042z$	0.089	0.749
Spruce-moss forest	over 1.5	$\log_{10} y = -1.47 + 2.626 \log_{10} x$	0.143	0.902
	under 1.5	$y = -0.076 + 0.003z$	0.033	0.862

* x = d.b.h. (cm), y = weight (kg), and z = height (cm)

Above-ground biomass and tree density estimates for black spruce in the six subarctic sites were as follows:

Site	Association	Number of trees per hectare	Breast height stem area (m^2/ha)	Above-ground *P. mariana* biomass (kg/ha)
1	Spruce-lichen woodland	1,270	2.38	9,590
2	Spruce-lichen woodland	3,080	11.83	21,060
3	Spruce-lichen woodland	2,510	16.14	29,250
4	Spruce-moss forest	4,840	19.50	82,270
5	Spruce-moss forest	5,095	36.61	163,360
6	Spruce-moss forest	5,350	20.13	78,360

1. MORRISON, I.K.

2. 1973

3. Distribution of elements in aerial components of several natural jack pine stands in northern Ontario.

4. Canadian Journal of Forest Research 3:170-179

5. a. Canada; Index map ML-17; Ontario

   b. Jack pine

   c. Biomass (tree)

6. Total above-ground standing crop of five macroelements, nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), were determined in natural jack pine stands of three age classes, 20, 30 and 65 years, growing along a portion of the Mississagi River in Wells Township, Ontario (45 25 N, 83 23 W). This area is within the Algoma section of the Great Lakes - St. Lawrence Forest Region.

Basic stand data, including numbers of trees per hectare, basal area per hectare, and above-ground dry-matter content were derived from Regyi (1972) as summarized in the table below:

Stand age	Site class	Stocking class	Stems/ha	Basal area (m^2/ha)	Dry matter (kg/ha)
20	I	high	2,224	4.8	13,207
		low	1,347	2.8	7,454
	II	high	1,940	5.9	16,002
		low	605	2.4	6,865
30	I	high	3,002	28.9	99,213
		low	1,137	16.6	63,434
	II	high	3,842	27.6	88,498
		low	1,742	17.6	61,000
65	I	high	568	23.7	105,783
		low	346	12.5	53,989
	II	high	519	17.8	76,046
		low	358	10.5	43,637

The author found generally low absolute quantities of all elements in the aerial parts of jack pine stands, which suggests either a low nutrient-accumulating ability for jack pine, or a low availability of elements within the ecosystem. Presumably, it is a low nutrient requirement that enables jack pine to maintain acceptable growth rates on sites of low fertility. Jack pine typically occurs on low fertility sites and, clearly, if all the overstory were removed, as in full-tree

Continued ...

logging, significant quantities of N, K, and Ca could be lost from the site. On such sites harvesting practices in which slash is left on site could be used to reduce substantially the drain on at least N and K, since considerable quantities of these elements occur in the crowns. The drain on Ca would not be alleviated since the greater part of that element is contained in the stems, although it should be added that deficiencies of Ca are, in any event, extremely unusual in conifers.

1. MORRISON, I.K.

2. 1974

3. Dry-matter and element content of roots of several natural stands of **Pinus banksiana** Lamb. in northern Ontario.

4. Canadian Journal of Forest Research 4:61-64

5. a. Ontario; Index map NL-17; Ontario

   b. Jack pine

   c. Biomass (tree)

6. The present paper is a companion to a previous report that described the content of dry matter and N, P, K, Ca and Mg in 30 to 35 year old stands of **Pinus banksiana** from the Algoma section of the Great Lake - St. Lawrence Forest Region in Ontario (45 25 N, 83 23 W). The root systems of eight trees were excavated, weighed, and analyzed for chemical content. Using the regression-stand table method, dry-matter and nutrient content per hectare were estimated.

Tap roots of the trees penetrated to a depth of 1.5 m; the number of principal lateral roots at the root collar ranged from 4 to 7. Total root dry weight increased logarithmically with increasing d.b.h. Total root dry weight for 30-year jack pine stands of various site and stocking classes were as follows:

Site class	Stocking	Total root dry weight (kg/ha)
I	high	15,932
	low	11,441
II	high	13,231
	low	9,886

The percentage of total dry matter that is below-ground (compared with above-ground figures for the same stands from Hegyi 1972) ranges from 13 to 14%. The author concluded that, at least in young stands, jack pine produces considerably more above-ground dry matter relative to below-ground dry matter, than other species. Quantities of minerals bound up in root tissue are small in comparison with those in the aerial parts. Considering the low quantities of elements bound up in roots of small diameters, it is not likely that root slough is a major medium of exchange. From a forest management standpoint, approximately 8% of stand N, 9% of K, 12% of P and Ca, and 16% of Mg would remain behind in stumps and roots after logging.

1. MOSKALYUK, T.A.

2. 1980

3. The amount and structure of the phytomass of stands in the main types of larch forests in the northern part of the Sea of Okhotsk region.

4. Lesovedenie (1980) 2:32-39

5. a. U.S.S.R.

   b. Larch

   c. Biomass (tree)

6. Measurements were made of biomass components of trees in the four commonest types of larch forest in the Magadan region of the U.S.S.R.: (a) **Laricetum mixtoherboso-equisetosum**, (b) **L. caricoso-sphagnosum**, (c) **L. hylocomioso-vacciniosum**, and (d) **L. vaccinioso-cladinosum**; the stands had **Pinus pumila** in the understorey. The results were tabulated and the difference between the phytomass on the best and the worst sites was more than 9-fold, the phytomass of (a) being 299.3 t/ha and that of (b) only 33.1 t/ha. Stemwood accounted for 42 to 57% of the total phytomass, the roots for 34 to 50% and the crowns for 5 to 10%.

1. **NATIONAL DEFENSE UNIVERSITY**

2. 1978

3. Climate change to the year 2000: a survey of expert opinion.

4. Conducted by the Research Directorate of the National Defense University jointly with the U.S. Department of Agriculture, Defense Advanced Research Projects Agency, National Oceanic and Atmospheric Administration, and Institute for the Future. Fort Lesley J. McNair, Washington, D.C. 109 p

5. a. Northern hemisphere

   b. nil

   c. Climatic change (hypotheses)

6. Controversy has arisen about whether the climate is merely fluctuating or is in a long-term trend of change. In view of the potentially serious implications of climatic change, the National Defense University in the fall of 1976 initiated an interdepartmental research project to quantify the likelihood of significant changes in climate and their practical consequences. This report presents the results of the first phase of the study, the definition and estimation of the likelihood of climatic changes during the next 25 years, and construction of climate scenarios for the year 2000. The expert opinions expressed in this report are based on responses to a structured climate questionnaire that was submitted to a carefully selected panel of climatologists.

This study was the first comprehensive attempt to quantify perceptions of climatic changes, and it's most salient finding is that there was a concensus that there is small likelihood of catastrophic climatic change by the year 2000. More specifically, the responses to the survey suggest only one chance in 10 that average global temperature in the next 25 years will increase by more than 0.6° C relative to the early 1970's. Likewise, there is only one chance in 10 that it will decrease by more than 0.3° C. The most likely event will be a climate that resembles the average of the past 30 years, arising primarily from a balancing of the warming effect of carbon dioxide with the cooling effect of a natural climate cycle. However, the respondents tended to anticipate a slight global warming rather than a cooling.

Most of the panelists perceived that any global temperature changes will be amplified at higher latitudes, particularly in the northern hemisphere. This magnification will be less pronounced in the southern hemisphere because the larger surface area of southern oceans provides more thermal inertia against change than is the case in the northern hemisphere.

The panelists' responses reflect fairly strong support for the continuation of a 20- to 22-year drought cycle in the high plains of the

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United States. The climatologists expressed considerable uncertainty about possible changes in the amount and variability of precipitation. This uncertainty was particularly pronounced about possible changes in year-to-year variability. There was, however, some tendency to associate more precipitation and decreased variability of precipitation with global warming, and less precipitation and increased variability with global cooling.

Perhaps more pertinent than a given change in average global temperature is the nonuniformity of the associated temperature changes at different latitudes. Global temperature fluctuations are expected to be far more pronounced in the polar regions than in low latitudes. In other words, the poles are perceived as more sensitive to climatic change. A number of respondents judged that the poles may experience a change at least several fold larger than the global average. It was suggested that although a temperature change per se does not imply increased climatic variability, there is some physical basis for saying that a general cooling would imply increased baroclinic instability and therefore increased temperature variability and vice versa.

One question put to the climatologists dealt with changes in the mean length and variability of growing seasons in the higher middle latitudes during the next 25 years as compared to the present. A majority of the panelists thought that there would be no significant changes in the mean length of the growing season and its interannual variability in the next 25 years. One respondent suggested that it is likely that the present meridional trend in atmospheric circulation (with longer growing seasons) will prevail for a few years, to be replaced later on by a return to zonal circulation, with shorter growing seasons. Over the 25 years the change might well even out.

One adherent to the idea of global warming indicated that if one plots growing season versus mean summertime temperature at mid-continental stations, one can deduce a rule of thumb that a change of plus or minus 1° C corresponds to about plus or minus 10 days in growing season. In 25 years the mean hemispheric temperature should rise about 1° C, and at middle and higher latitudes the corresponding change should be several times larger. Thus, it would be possible to have a greater than 10-day increase in growing season at middle and high latitudes. Another advocate of global warming stated that, consistent with a general warming to be anticipated with the CO_2 increase, which would be largest in the high latitudes, one could expect a higher probability of a lengthened growing season than that inferred from climatological averages. The interannual variability of the growing season length would not likely change by more than 25% but such changes as there may be are more favored to be in the direction of a decrease than otherwise because the CO_2 increase itself might be expected to discourage very low temperatures more than at present.

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National Defense University. 1978. Continued

Notwithstanding the panelists' collective uncertainty about the growing-season expression of temperature variability, one can infer a tendency to associate greater variability of temperature with extreme global cooling and less variability with extreme warming. A similar inclination to associate more variability with cooling and less with warming emerged in the questions relating to precipitation.

A number of prominent climatologists have stated that world weather patterns in the near future are very likely to become less stable, and more variable from year to year. However, many of the panelists commented on the lack of sufficient actual experience, comprehensive theories, or adequate models to support their estimates.

The compilers of this report concluded that, given panelists' diverse comments about variability and some tendency to associate greater variability of precipitation and length of growing season with global cooling, and less variability with warming, the direction and magnitude of trends are obviously in dispute.

One panelist pointed out the importance of distinguishing climate variability and fluctuations with respect to different time scales, by suggesting that there are two pertinent time ranges of variability, one on the scale of months and seasons within the year, and the other involving long-term droughts over periods of years. This same panelist thought that at the present time the westerlies are shifting from the higher middle latitudes towards lower middle latitudes, bringing with them more of the temporary but severe drought and severe cold, including early and late killing frosts. This raises the possibility that the higher middle latitudes, particularly in Canada, from which the westerlies are being displaced, are likely to suffer increased incidence of the long-term type of drought and cold.

1. **NICHOLS, Harvey**

2. 1975

3. Palynological and paleoclimatic study of the late Quaternary displacements of the boreal forest-tundra ecotone in Keewatin and Mackenzie, N.W.T., Canada.

4. Institute of Arctic and Alpine Research, University of Colorado, Boulder. Occasional Paper No. 15. 87 p

5. a. Canada; Index maps NQ-9/10/11/12, NP-12/13, NP-13/14; District of Mackenzie, District of Keewatin; B.27, B.32

   b. Birch, Pine, Spruce

   c. Climate/growth (indirect influences), Climatic change (proxy data), Treeline studies (climate)

6. The paragraphs below are based upon excerpts from the author's summary.

A series of six pollen diagrams were prepared from peat profiles from four sites along the Canadian boreal forest-tundra ecotone to detect ecotonal displacements due to climatic changes. The four study sites were Port Radium (66 N, 118 W), Coppermine (68 N, 115 W), Thomson Landing (63 N, 111 W) and Ennadai Lake (61 N, 101 W). Two additional short profiles from Baffin Island were prepared to examine the sensitivity of such analyses to influx of exotic forest pollen due to paleowind shifts and forest displacements. Bryson's (1966) hypothesis of the control of northern forest by the mean summer position of the arctic front was used throughout.

Palynological interpretation was assisted by use of absolute as well as relative counts, by comparison of fossil data with numerous modern pollen counts from Tauber traps and moss and lichen polsters, by peat stratigraphic analyses, and recognition of plant macrofossils. Changes in peat type and rates of growth were strongly indicative of environmental/climatic changes.

The broad outline of the climatic changes is summarized in the following paragraphs.

The oldest sediments dated back to 6200 BP in an area deglaciated about 8000 BP and represented a spruce forest environment substantially warmer in summer than now. This hypsithermal warmth continued until 4800 BP, with possible evidence of cooling at 5600 to 5500 BP and a maximum of summer warmth from 5300/5200 BP to 4800 BP.

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Nichols, Harvey. 1975. Continued

A cold summer episode from 4800 BP for several centuries expanded tundra almost down to its modern limit, and recovery took place between 4500 and 4250 BP, depending on lag in plant colonization. At 4200 BP there was a brief cooling, followed by a peak of summer warmth around 4000 to 3900 BP. From about 4000 to 3000 BP there were frequent forest fires throughout the northern forest. The forest was able to recover from these until 3500 BP when widespread and broadly synchronous fires swept the ecotone from one end to the other over a period of 100 or 200 years. These fires were due to summer expansion of cold dry arctic air masses over the northernmost forest, which then changed to tundra until 3300 BP. By 3200 BP some woodland regeneration registered milder summers, but by 3000 BP tundra expanded southwards in a prolonged episode of colder summers. Further cooling at 2500 BP forced another southward ecotonal retreat and damaged the tundra plant cover so that windblown sand was incorporated in peat.

Maximum cooling occurred at 2200 to 2100 BP. When warming followed, vegetation recovery was registered at several dates between 2000 and 1500 BP, due probably to plant migrational lag. Brief cooling occurred at 1400 BP. Warming around 1200 to 1000 BP allowed a minor woodland advance, followed by a major cooling after 800 to 600 BP which caused a major forest retreat. Many peat profiles ceased growth and have not regenerated since. Some minor warming may have been registered within the last 150 years at a minority of sites.

A survey of eight ecotonal pollen diagrams spanning 1400 km from east to west from the west shore of Hudson Bay to beyond Great Bear Lake, demonstrated clear synchrony and parallelism in the movement of this boundary in response to climatic changes over at least the last 600 ^{14}C years. There is some preliminary evidence that may indicate a greater amplitude of Holocene ecotonal displacement in the continental interior of Keewatin and Mackenzie than in northwest Canada, possibly 400 km as compared to about 250 km. This was presumably due in the northwest to diminished movement in the upper atmospheric ridge due to compression between the Cordillera and the cold Arctic Ocean. These circumstances may imply that the Canadian northwest was less sensitive to paleoenvironmental change than the continental interior.

An apparently normal aspect of the ecotonal forest ecosystem was the instability brought on by fairly frequent major fires at intervals of one to two centuries, from which the forest recovered usually within fifty years during long episodes of favourable climate. It is tentatively deduced from pollen diagrams that sizable areas of open woodland, for example north of Great Bear Lake, may be out of equilibrium with the modern climate and may be overdue for a major fire, after which the trees might be replaced by shrub tundra.

1. NICHOLS, Harvey

2. 1976

3. Historical aspects of the northern Canadian treeline.

4. Arctic 29:38-47

5. a. Canada; Index maps NQ-9/10/11/12, NP-12/13, NP-13/14; District of Mackenzie, District of Keewatin; B.27, B.32

   b. Black spruce, white spruce

   c. Climatic change (hypotheses, proxy data), Treeline studies (climate)

6. From palynological studies it appears that northernmost dwarf spruces of the tundra and parts of the forest tundra boundary may be relicts from times of prior warmth, and if felled might not regenerate. This disequilibrium may help explain the partial incongruence of modern climatic limits with the present forest edge. Seedlings established as a result of recent warming should therefore be found within the northernmost woodlands rather than in the southern tundra.

The history of the northern woodland provides numerous instances of cold, dry climatic episodes having been followed by fires after which the trees did not become re-established until the summer climate became warmer. The domination of the woodlands by increasingly frequent incursions of air from the Arctic in summer is thought to lead to desiccation, with increased likelihood of fire. It would appear from this hypothesis that the present-day woodlands north of Great Bear Lake and elsewhere may be susceptible to eradication by fire and replacement by shrub tundra. The process is an example of vegetational inertia in the face of environmental change due to the buffering effect of the local forest climate.

The northernmost spruce outliers or "tree islands" may be regarded as relicts of consistently warmer summers in the past. Bryson (1966) and Barry (1967) have examined the degree of coincidence of the mean summer location of the Arctic Front with the forest-tundra boundary, and suggest that the cold dry arctic airmass inhibits the northward penetration of trees into the tundra, which implies that the summer position of the front must previously have moved sufficiently far north to allow sexual reproduction of spruces. From this hypothesis, it may be deduced that the mean summer position of the Arctic Front must have approached the present tree-species limit at some time during the Holocene. Any spruce seeds which were blown farther north presumably would not consistently reproduce under the summer conditions of the arctic climate.

Two likely developments are suggested. The first involves brief climatic warmings when spruce seeds, transported north along waterways by flotation or wind dispersal over ice or snow crust, became established along rivers and lakes as isolated spruce colonies within the expanded

Continued ...

Nichols, H. 1976. Continued

Pacific airmass zone; and colder, drier summers followed the southward movement of arctic airmasses and prevented expansion of these outliers. The second possibility is that, during prolonged periods of warmer summers, the forest ecotone moved north to include the modern "tree islands", and then retreated to leave the most protected, moist waterway sites occupied by spruce for up to several thousand years. While the first explanation is the least demanding of environmental change, there is evidence that the second applies to a number of fossil forest sites not situated on waterways, where spruce wood and needles along with abundant preserved Picea pollen provide a record of the former existence of spruce forest in present-day tundra.

It follows that even if, due to migrational lag, there was an insufficient interval of warming for the entire forest edge to move north to surround the spruce outliers, there was still a massive northward summer extension of the boreal forest climatic zone, or "potential forest zone" - the zone of Pacific, modified arctic and indeterminate air, according to Bryson (1966).

In a related matter, there is currently some uncertainty about the apparent lack of clear response of the Canadian boreal forest-tundra ecotone to the instrumentally-recorded summer warming during the nineteenth and twentieth centuries. During extensive fieldwork in the region, Larsen (1965, 1972, 1974) found that spruce seedlings did not grow consistently successfully in the southern reaches of the tundra. The modern climatic warming may have been too small to move the "seedling treeline" northwards beyond the present woodland-tundra ecotone which was previously established under substantially warmer conditions. Thus, the hypothesis of the historically-established position of some modern treelines implies that a consistently successful establishment of spruce seedlings due to the recent warming should also be searched for within the present northern woodlands, not just in the southern tundra.

Higher ground north of treeline in the Canadian northwest is a possible explanation for the inhibition of northward forest expansion. Two other factors are probably involved: the effect of the Arctic Ocean in depressing summer temperatures, and the "anchoring" effect of the northern cordillera on the upper atmospheric westerly waves. Thus, while movements of the arctic front and the forest limit tend to be quite restricted in the northwest, they both readily vary their positions in the continental interior.

1. NICHOLSON, J. and D.G. BRYANT

2. 1972

3. Climatic zones of insular Newfoundland: a principal component analysis.

4. Department of the Environment, Canadian Forestry Service, Publication No. 1299 13 p

5. a. Canada; Index maps NK/NL-21/22, NM-21-22; Newfoundland; All boreal forest sections in Newfoundland

   b. Nil

   c. Climate (temperature), Climatic variation (regional, temperature, precipitation)

6. Biologists often relate the distribution and behaviour of organisms to climatic factors. These factors, however, are numerous and their relations are complex; hence, meaningful analysis has frequently been difficult. Principal component analysis (PCA) is a multivariate statistical method that reduces many variables and complex relations to a few meaningful factors. This paper presents the results of a PCA of climatic data for insular Newfoundland. It presents the results in terms of already known climatic variation and in relation to forest sections. The authors also suggest the most pertinent climatic variables to use in biological studies on the island, and outline some possible applications to forestry.

The dominant local influence on climate is the Labrador Current, which virtually encircles the island. Because of sea ice, temperatures are low even in June or early July on the north and east coasts. The temperature pattern is altered in summer because the prevailing southwest winds, which pass over the Labrador Current where it flows along the south coast, cause temperatures in southern areas to be cool. These winds gain heat while passing over the central land mass and, as a consequence, there is a paradoxical trend of increasing temperature towards the more northern latitudes of the island except on the Northern Peninsula, where temperatures decrease northward because of the proximity of the Labrador Current. The Northern Peninsula is unique because of its extremes in climate. For instance, potential evaporation ranges from 48 cm in the south to 38 cm in the north, over a distance of 240 km; a similar transition in Quebec occurs over a distance of about 1,100 km. Hare (1952) also noted the comparative wetness of the south coast of Newfoundland and the generally longer frost-free periods in the southern and eastern areas of the island.

The climate of insular Newfoundland is variable, but through the use of PCA it was possible to group stations, designate climatic zones for the island, and describe the climatic pattern in each zone. In addition, analysis showed which of 25 variables best described the variability of

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Nicholson, J. and D.G. Bryant. 1972. Continued

climate. The stations that were grouped together by PCA agreed remarkably well with the island's boreal forest sections.

Reasons for transitions or local variations in biological phenomena may be indicated by the dissimilarity in climate of a station with respect to others in the same forest section. For example, the balsam wooly aphid, **Adelges piceae**, had caused little damage to the forest immediately north of Deer Lake but extensive damage in nearby forests to the southwest. This difference in the extent of damage might be the result of cold-season climatic conditions as recorded at Deer Lake. Cold-season temperatures are known to limit aphid distribution geographically and consequently this climatic analysis may be useful for predicting the eventual distribution of aphid damage in the Grand Falls Forest Section (B.28a). For example, aphid damage may be innocuous in the vicinity of Glenwood, which has lower cold-season values than at Deer Lake, but serious at Grand Falls, which has higher values.

1. **HENDRIKS, Lawrence C. and Lena WEBER**

2. 1976

3. Wet and dry sequences in precipitation regimes.

4. Geografiska Annaler 58A:303-315

5. a. Canada; Index maps NN-11, NN-12, NO-11, NO-12; Alberta; B.17, B.18a, B.18b, B.19a, B.19c, B.22a

   b. Nil

   c. Climatic variation (regional, temporal, precipitation)

6. Precipitation series in many climates show fluctuating periods of wet and dry regimes. Although there have been attempts to explain such fluctuations, none of these efforts has been completely successful. An alternative procedure is to simulate the past precipitation regime and to infer future processes from the resulting function. This study used such an approach for the province of Alberta.

Within Alberta, the complex mountain region has the highest mean annual precipitation and the greatest year-to-year variability. The central region of the province, which is dominated by the Alberta storm track, shows the greatest consistency in annual precipitation. The dry belt of southeast Alberta is variable but to a lesser degree than the mountain zone. There is a weak inverse relationship between the westerly component of surface winds and annual precipitation.

The authors classified the years from 1925 to 1972 as abnormally wet, abnormally dry, or average for each of the north, central and southeast zones within Alberta. In 1935, the north and central regions of the province were very wet, while the southeastern portion was very dry. Only in two years, 1932 and 1951, did all three zones experience abnormal wetness.

The authors concluded that province-wide wet and dry years were the exception rather than the rule.

1. OLSON, Jerry S.

2. 1975

3. Productivity of forest ecosystems.

4. IN: Productivity of world ecosystems, Proceedings of a Symposium presented at the V General Assembly of the Special Committee for the International Biological Program. National Academy of Sciences, Washington, D.C. p 33-43

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb, moss/lichen)

6. The author's two hypotheses were that woodlands have (1) a predominant part of the whole biosphere's live biomass, and (2) a higher biological production than other biomes. In general, both hypotheses were confirmed by this article's tabular estimates of biomass and production in forest ecosystems.

The author summarized the areal extent, biomass and net primary productivity of boreal subzones as follows.

	Area (10^6 km^2)	Dry live Plant mass (t/ha)	Total Biomass (10^9/t)	Net Primary Production (t/ha/yr)
Northern taiga parkland: glei podsols	0.880	125	11.00	5.0
North, middle taiga woodland: permafrost	2.463	200	49.26	6.0
Middle taiga woodland: podsolic soils	3.571	260	92.85	7.0
Southern taiga forest: sod-podsolic soils	3.182	300	95.46	7.5
TOTALS	10,096		248.57	

Investigators in the U.S.S.R. estimated less than 500 g/m^2/yr of production and less than 7,000 g/m^2 of biomass for tundras and bogs. In contrast, northern, middle and southern taiga zones have average productivities ranging from 500 to 750 g/m^2/yr but live biomass (including estimated roots) increases even more from 12,500 to 30,000 g/m^2 as one progresses southward within the taiga zone. By multiplying land area times mass per unit area and summing over zones, the author obtained an estimate for taiga of over 6.8 x 10^9 t/yr as the production rate (net primary productivity) and a live organic mass of

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2.5 x 10^{11} t. For the varied systems lumped as "semiboreal", including extensive birch, aspen and some other hardwoods, the total production rate was estimated as over 4.20 x 10^9 t/yr by an inventory of about 1.3 x 10^{11} t.

The author made preliminary estimates of organic carbon inventory and exchange based on assumptions of carbon percentages ranging from 43 to 49% for major plant parts. The relative importance of the boreal forest in this context, and in comparison to the total land area of the earth, was estimated as follows.

	Carbon production (10^9 t/yr)	Live carbon pool (10^9 t)	Turnover* function per year
Total Boreal	3.33	121.80	0.0275
TOTAL LAND	75.35	1,070.00	0.07

* Annual loss of carbon from the live carbon pool to dead organic matter.

Annual turnover, in terms of the net primary production and equivalent loss of plant organs, is apparently only a few percent of the biomass or carbon inventory for all but some tropical forests.

1. [redacted], William, J.

2. 1980

3. Socioeconomic impact of climate on forestry in Alberta.

4. IN: J.M. Powell, Compiler, Socioeconomic impacts of climate. Proceedings of the workshop and annual meeting of the Alberta Climatological Association. March 1979. Environment Canada, Canadian Forestry Service, Northern Forest Research Centre, Edmonton. Information Report NOR-X-217, p. 13-17.

5. a. Canada; NO-11, NO-12, NM-11, NM-12, NH-11, NH-12; Alberta; B.17, B.18a, B.19a, B.19c, B.23a

   b. Aspen, White spruce,

   c. Climate/growth (direct relationships), Forest growth and yield

6. The author used existing forest inventory information to divide Alberta into five economic macroregions that were not given names by the author but which were numbered and located as follows: 1. mountains and foothills region; 2. central and southern Alberta region east of the foothills; 3. northeast region centering in oil sands area; 4. northwest region centering in Peace River area, and; 5. northern region. On medium sites in these macroregions the average merchantable height and merchantable volumes varied with climate, in particular with the length of growing season or frost-free period.

Although no biomass data were provided in this report, merchantable volumes and average heights of mature white spruce and aspen in each of the five macroregions are summarized in Table 1.

In parts of Alberta, the map of natural forest growth potential provided an excellent correlation with broader climatic regions based on Powell's (1978) climate groups for the forested regions of Alberta.

Table 1. Average height and merchantable volume in mature stands of white spruce and aspen.

Macroregion	Average height of mature trees (m)		Merchantable volume* in mature stands (m^3/ha)	
	White spruce	Aspen	White spruce	Aspen
1	12.2	14.3	39.5	55.8
2	22.2	22.9	139.4	157.4
3	19.8	19.8	122.6	145.5
4	21.3	22.9	131.2	133.7
5	19.8-22.9	22.2	122.3-146.8	91.7

* Based on trees 10.2 cm in diameter at breast height and larger.

1. OSWALT, W.H.

2. 1958

3. Tree-ring chronologies in south-central Alaska.

4. Tree-ring Bulletin 22:16-21

5. a. Alaska

   b. White spruce

   c. Climate/growth (direct relationships), Treeline studies (climate, growth)

6. This paper describes tree-ring chronologies of white spruce in south central Alaska. The elevations of the white spruce stands sampled ranged from river valleys to altitudinal treeline. Three of the six sampled stands had tree-ring chronologies characteristic of the 'Series A Dating' described by Giddings (1941). A direct positive correlation between a small ring in a treeline spruce and low temperature for June and July has been demonstrated in Alaska. Two of the stands located near altitudinal treeline had ring patterns with few rings diagnostic of the 'Series A Dating'. The locations of these stands in narrow wind-swept passes are believed to be responsible for the unique tree-ring patterns.

Tree rings in one of the six stands sampled crossdated among themselves but had no overall correspondence with any other dating series. The author suggested that more extensive sampling of white spruce would reveal that this distinctive ring sequence would be found over a wider area.

1. OSWALT, W.H.

2. 1960

3. The growing season of Alaskan spruce.

4. Tree-Ring Bulletin 23:3-9

5. a. Alaska

   b. White spruce

   c. Climate/growth (direct relationship), Growing season (length), Treeline studies (growth)

6. The author examined relationships between the duration of yearly growth in Alaskan white spruce and temperatures during the period of cell multiplication. It has been noted repeatedly in Alaska that there is a positive correlation between a year with low summer temperatures and a narrow radial growth increment, whereas a large ring tends to reflect a summer with relatively high mean temperatures.

White spruce were sampled at locations from a valley bottom in the interior and at treeline along the Bering Sea coast. In all the sampled areas cells were added over a growing season that ranged from 50 to 60 days. Growth began as early as the middle of June and extended as late as the latter part of August. Most growth occurred in the period from 5 July to 5 August. It was apparent that the growing season, on the whole, was later for treeline spruce of western Alaska than for those of the valley bottom in interior Alaska. The data also suggested that there was a direct and positive correlation between low temperatures during the growing season and a decrease in cell multiplication.

Several other studies of seasonal growth were cited by the author. Marr (1948) studied seasonal growth in spruce, mainly white spruce, near the tundra zone on the east side of Hudson Bay, where ring formation began early in July and extended through the month of August. Belyea, Fraser and Rose (1951) studied trees from two localities in Ontario. White spruce at Chalk River, Ontario began growing 11 May, and at Cedar Lake, Ontario growth began 29 May. The period of growth lasted 100 days in both case . Giddings (1941) concluded that valley bottom trees of interior Alaska complete most of their growth in June with the final cells being added in early July. Treeline spruce of interior Alaska added their annual ring from approximately mid-June to mid-July. In both cases, growing seasons were approximately 30 days.

Studies in Scandinavia have also shown the correlation between June and/or July temperatures and the proportion of radial growth in conifers. The period of sufficient temperature and annual growth are not identical. The influential temperature period is June and July whereas most annual growth takes place in July and August. Further inquiry was suggested to validate the hypothesis of a lag between temperature and growth for trees in Alaska.

1. OTTESTAD, P.

2. 1979

3. The sunspot series and biospheric series regarded as results due to a common cause.

4. Meldinger fra Norges Landbrukshøgskole 58. 20 p.

5. a. Norway, Great Britain

   b. Scots pine

   c. Climatic change (hypotheses, dendrochronology, proxy data)

6. Step-wise regression analyses were used to examine the cyclic nature of seven long-term series of data: sunspot activity (from 1700); ring-width data for Scots pine in Norway (from 1730); annual yield of barley in England and Wales (from 1884); annual mean temperature in the soil in Norway (from 1903); annual mean temperature in the air in Norway (from 1870); annual rainfall in the East Midlands, England (from 1726); and annual yield of the Lofoten cod fishery, Norway (from 1885). The author found some evidence for cyclic activity and suggested that the phenomena observed are related to a common cause, such as the cyclic nature of the solar energy stream.

1. ØYSTEDAL, Dag Olav

2. 1980

3. Plantebiomasse i li-gråorskog i Troms [Plant biomass above ground in an **Alnus incana** hillside forest in inner Troms, North Norway]

4. Blyttia 38:209-213

5. a. Norway

   b. Hil

   c. Biomass (shrub/herb)

6. This paper describes the results of a study of biomass in the field (herb) layer of an **Alnus incana** stand in northern Norway. The sum of the field layer biomass, dry weight, was 156.8 g/m^2 in 1975, 277.8 g/m^2 in 1976, and 258.4 g/m^2 in 1977. The sum of growth units (undefined by the author) for June, July and August showed a linear correlation with the biomass of the field layer. The **Alnus incana** biomass above ground was estimated to be 8.5 kg/m^2 for the study area.

1. PAKARINEN P. and R.J.K. RINNE

2. 1979

3. Growth rates and heavy metal concentrations of five moss species in paludified spruce forests.

4. Lindbergia 5:77-83

5. a. Finland

   b. Norway spruce

   c. Biomass (moss/lichen)

6. Growth rates and metal contents (Fe, Mn, Zn, Pb, Cu) of moss carpets were studied in the southern boreal zone of southern Finland in seven **Picea abies** forests with a thin peat layer. The increment lengths for 1976 and 1977 were greater in the species that grew in wet microhabitats (**Sphagnum girgensohnii**, **Polytrichum commune**) than in species of drier microsites (**Hylocomium splendens**, **Pleurozium schreberi**, **Dicranum majus**).

The net annual production of dry matter in **Pleurozium** stands was on average 98 $g/m^2/yr$ and a range of 41 to 161 $g/m^2/yr$ was recorded. These values refer to moss stands with nearly continuous (90 to 100%) coverage and are comparable to previous results for boreal forest mosses. The average production of **S. girgensohnii** (191 $g/m^2/yr$, with a range of 110 to 313 $g/m^2/yr$) was significantly greater than that of **Pleurozium**. The values are very close to the results reported for **Sphagnum fuscum**, a hummock species of treeless or semi-open ombrotrophic bogs.

In boreal forests, the dead moss stems remain unbroken for a few years and thus the total age of the moss layer (including the brown portions where moss leaves are at least partially intact) is distinctly higher than the age of the green top portion. Usually the transition from moss carpet to the F-H layer of soil is very gradual. The total age of moss carpet was estimated in **Dicranum majus** to be from 2 to 4 yr, in **Pleurozium schreberi** from 2.5 to 5 yr and in **Hylocomium splendens** from 3 to 5 yr. Of the studied mosses, the stems of **Polytrichum commune** appeared to be most resistant against decomposition.

1. PARKER, M.L.

2. 1976

3. Improving tree-ring dating in Northern Canada by X-ray densitometry.

4. Syesis 9:163-172

5. a. Canada; Index maps NR-7/8/9, NP-9/10; District of Mackenzie; B.32, B.33

   b. White spruce

   c. Climate/growth (direct relationships), Climatic change (dendrochronology), Climatic variation (regional)

6. It is well known that some forest regions are better than others for producing usable tree-ring samples for archaeological dating and for reconstruction of past climatic history. The semi-arid conditions of the southwestern United States provide the climatically sensitive tree-ring chronologies and the proper conditions for wood preservation required for this type of research. The forested region near the treeline in northern Canada and Alaska is also an area where archaeological tree-ring dates can be obtained fairly easily and where the building of long, climatically sensitive tree-ring chronologies is possible. In semi-arid regions, widths of annual rings are closely related to available ground moisture, but Giddings noted that, near the northern limit of the forest, temperature is the most important limiting factor and tree-ring widths correlate well with summer temperature.

For the present study, ring-width and ring-density chronologies were built from increment cores taken from white spruce trees growing in two areas - near the town of Inuvik, in the Mackenzie Delta, and Nahanni Butte mountain site, near the village of Nahanni Butte in the southwestern corner of the Northwest Territories. The recent development of X-ray densitometry has increased the potential of obtaining dates for archaeological tree-ring samples. X-ray densitometry permits the analysis of annual-growth increments by intra-ring density as well as by width variables. This leads to a better understanding of the relationships between tree growth and climatic factors.

Cross-correlation comparisons were made on a year-to-year basis for each of the 12 intra-ring variables with total monthly precipitation and mean air temperature for each of the five months from May to September for both the Inuvik and Nahanni Butte tree-ring sites. The following conclusions for these particular sites can be drawn.

1. Tree-ring variables for both sites are more closely related to temperature than to precipitation.

2. Density parameters generally relate more closely to climate than do width variables, but both width and density correlate well for temperature for the Inuvik series for the months of July and August.

Continued ...

3. There are a number of significant correlations for comparisons of temperature and width variables for the months of June and July for the Fort Simpson-Nahanni Butte area, and for the months of July and August for the Inuvik area. This suggests that the increment response of trees to temperature occurs later at Inuvik than at Fort Simpson.

4. Although the data are inadequate to confirm it, there is a suggestion that the correlations are stronger for a comparison of ring variables and weather factors for the Inuvik area than for the Fort Simpson area.

The author indicated that the quality of the master tree-ring chronologies for dating archaeological samples from northern Canada will be improved as more samples are incorporated into the master series and as older trees are dated and processed.

1. PASTOR, John and J.G. BOCKHEIM

2. 1981

3. Biomass and production of an aspen - mixed hardwood - spodosol ecosystem in northern Wisconsin.

4. Canadian Journal of Forest Research 11:132-138

5. a. Wisconsin

   b. Aspen

   c. Biomass (tree)

6. Total biomass of an aspen - mixed hardwood - spodosol ecosystem in northern Wisconsin (45 50 N, 89 40 W) was 197 t/ha and net primary production was 11.5 t/ha/yr. Aspen (**Populus tremuloides**) accounted for 60% of the total biomass and 56% of the annual production and sugar maple (**Acer saccharum**) accounted for 25% of the biomass and 28% of the annual production. For all species combined, bole wood was 63% of the total biomass and bole bark was 12%. Bole wood was 33% and bole bark was 7% of the total production. Although crowns accounted for only 15% of the total biomass, they were responsible for 49% of net annual production. Using allometric equations from the literature, root biomass and production were calculated as being approximately 10% of the total biomass and of the annual production. The average rate of total production per unit leaf tissue was 5.7 g production/g leaf tissue for aspen and 3.7 g/g for maple.

Differences between the two species are more apparent in the net annual production equations. The maples show a wider range in production than the aspen. This difference is due to the fact that all aspen receive roughly equal amounts of light while maples receive various amounts of light depending on canopy position.

At smaller diameters, production of all components by aspen is greater than production by maples. However, at large diameters, production by aspen is less than production by maples. These changes in relationship of production to d.b.h. occur somewhere between 18 and 25 cm for wood, bark, and total above-ground production, but the change occurs at a somewhat smaller diameter for crown production.

Production of a 25 cm sugar maple was estimated to be 33.9 kg/yr, while that of a 25 cm aspen is 17.6 kg/yr. Production by the maple is 1.9 times higher than production by the aspen. However, the rate of production per unit leaf weight of the codominant maple is 5.7/4.2 = 1.4 times lower than that of the aspen. Therefore, the maple must have 1.9 x 1.4 = 2.7 times as much leaf biomass as the aspen. From the leaf biomass regressions, the leaf weight of the aspen would be 3.0 kg while the leaf weight of the maple would be 7.7 kg, or 2.6 times greater than

Continued ...

that of the aspen. Thus, considerations of photosynthetic efficiency and total production closely predict the leaf biomass requirements of a tree.

Differences noted between aspen and maple may not be apparent in other stands composed of species more alike in silvical characteristics. In addition, such differences may not occur in more open stands in which more light penetrates the canopy. The authors indicated that additional work is needed to determine the effect of site quality on allometric relationships for different species.

1. PATERSON, Sten Sture

2. 1978

3. The forest area of the world and its potential productivity.

4. IN: H.F.H. Lieth, Editor, Patterns of primary production in the biosphere, Benchmark Papers in Ecology/8, Dowden, Hutchinson and Ross, Inc. Stroudsburg, Pennsylvania. p. 240-247

5. a. Northern hemisphere

   b. Nil

   c. Climate/growth (direct relationships, latitude)

6. This paper discusses the background theory behind Paterson's CVP (climate-vegetation-productivity) index. Temperature, precipitation and light are the three climatic factors most important for growth of plants. From these factors it should consequently be possible to obtain a value for the "plant growth ability" of a climate. Because of the intimate connection between climate, vegetation and productivity the index has been called the CVP-index after the initials of the three words.

In the equation, the need of plants for warmth must be represented by means of temperature figures, which are of different kinds: annual averages, monthly averages, extreme values, or ranges. The values that have proved to be most useful are temperature of the warmest month (Tv) and the annual range (Ta). The former represents the growth-promoting power of temperature. The latter, placed in the denominator of the fraction, is a reducer representing the inhibiting effect on vegetation caused by low values of temperature.

The supply of water is best expressed by annual precipitation (in mm). Its importance for vegetation increases with amount of rainfall and number of rainy days during the year. However, in the author's index calculations it proved that an increase in precipitation values did not have an unlimited effect on productivity. The effect of precipitation seems to have an upper limit as far as the amount of rainfall is concerned. If this value is exceeded, it will not cause a corresponding increase of productivity - rather, a decrease of productivity can be presumed, especially where extremely high rainfall figures prevail, as a result of leaching of nutrients.

From temperature and precipitation figures the length of the growing season (G) can be determined. The growing season has been taken by the author as the time during which the monthly average temperature reaches or exceeds 3° C. In warm temperate to tropical regions where the average temperature of the growing season never falls below 3° C, the growing season has to be calculated by methods involving precipitation data.

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The third important vegetation factor, light, is more difficult to put on a numerical basis in a way useful for the equation. The author has attempted to use number of hours when the sun is above the horizon during the year as well as during the growing season - both calculated as a percentage of total number of hours of the year - but the result has not been altogether satisfactory. The effect of light changes with the seasons, and will thereby be related to temperature conditions. The latter can therefore be supposed to express the effect of light conditions on vegetation.

The formula of the CVP index, I, is as follows:

$$I = \frac{Tv \times P \times G}{Ta \times 12}$$

Where Tv = mean monthly temperature (°C) of warmest month;
P = mean annual precipitation (mm);
G = growing season, defined as the number of months with a mean monthly temperature equal to or higher than 3° C
Ta = difference (°C) between the mean temperatures of the warmest and coldest months

This index shows a good correlation between values of ideal site class and index values. A map of global forest productivity patterns predicted by the CVP index is included with the article. An isoline of 25 for the value of the CVP index represents the climatic treeline. Most of the boreal zone is within index values of 25 to 100, corresponding to 0 to 5 m^3/ha of forest productivity.

1. PAYANDEH, Bijan

2. 1973

3. Analyses of a forest drainage experiment in northern Ontario. I. Growth analysis.

4. Canadian Journal of Forest Research 3:387-398

5. a. Canada; Index map NM-17; Ontario; B.4

   b. Black spruce

   c. Climate/growth (indirect influences, microclimate)

6. Most of Ontario's black spruce stands grow on peatland sites. Because of excess water, poor aeration, inadequate nutrient availability, and adverse climatic conditions the productivity of this species on organic soils is very low. However, it can be improved by draining, fertilization and thinning.

This paper presents a growth analysis of a forest drainage experiment carried out over 40 yr near Iroquois Falls, Ontario (48 40 N, 80 40 W). It is based on remeasurement data obtained in 1969 from 38 growth plots established following drainage in 1929 and from increment cores and sectioned trees. The author concluded that both diameter and height growth and, therefore, volume of individual trees of submarginal peatland black spruce can be improved significantly by draining. Response to draining will be higher for younger trees growing on better sites and having larger crowns than for trees on poor sites. Depending upon site quality, the effects of draining on individual tree diameter growth will be greatest not for those trees with the shortest distance of water flow to the ditch, but for those that are some distance from the ditch. This is perhaps caused by overdraining, compaction of spoil banks, and disturbance of tree roots nearest the ditches.

The author stressed that there remain many unknowns concerning the biology, physiology and chemistry of forest drainage that must be resolved before flexible growth-prediction models can be developed.

1. PAYETTE, Serge

2. 1974

3. Classification écologique des formes de croissance de Picea glauca (Moench.) voss et de Picea mariana (Mill.) BSP. en millieux subarctiques et subalpins.

4. Naturaliste Canadien 101:893-903

5. a. Canada; Index maps NO-18, NN-18; Quebec; B.13a, B.32

   b. Black spruce, white spruce

   c. Climate/growth (indirect influences), Treeline studies (climate)

6. White spruce and black spruce are characterized by many growth forms in the forest-tundra transition zone. This paper describes the most frequent growth forms in a study area between Poste-de-la-Baleine (55 17 N) and Boniface (57 48 N) and across nearly three degrees of longitude (74 45 W to 77 00 W). These growth forms may be individuals or agglomerated into krummholz. They express a climatic gradient determined by exposure to cold and erosive winds and by snow conditions during the colder period of winter. Desiccation and icing may act also in the genesis of growth forms. From exposed to protected sites, one can observe the successive dominance of mat, infra-nival, supra-nival skirted, verticillate, flag and tree growth forms. These growth forms are not static since the environment is normally fluctuating and they can evolve according to the importance of ecological changes.

1. **PAYETTE, Serge**

2. 1980

3. Les grandes crues glacielles de la rivière aux Feuilles (Nouveau-Québec): une analyse dendrochronologique.

4. Le Naturaliste canadien 107:215-225

5. a. Canada; Index map NO-19; Quebec; B.32

   b. Larch, black spruce

   c. Climate/growth (indirect influences), Climatic change (dendrochronology, proxy data)

6. Tamarack and black spruce populations located in the Leaf River floodplain are affected by ice-floods. A dendrochronological analysis of 150 trees with ice scars has provided the dates of major ice-floods along the mid-section of this river since 1850. The registered ice-floods had a mean interval of 11 yr during the 19th century (tentatively) and a 10-yr mean interval during the 20th century. The presence of many ice scars on the same stem allowed an evaluation of the importance of the 1934 and 1979 ice-floods. Both these floods had about the same amplitude, and reached at least 4 m above the lowest summer water level; these two catastrophic floods strongly disturbed the vegetation and soils of the floodplain. Available climatic and hydrological data suggest that major ice-floods occur mainly during cold periods characterized by a mean annual temperature below the general trend, abundant snow precipitation, and an early sometimes rainy spring. Low temperatures in the months and even the year preceding ice-floods might amplify the floods, especially in areas such as the Leaf River where permafrost favors runoff during snowmelt. The author suggests that data on ice-flood frequency and ice-flood amplitude obtained from dendrochronological analysis may be valuable for river management and for ecological studies of fluvial system dynamics.

1. **PAYETTE, Serge** and **GAGNON, Réjean**

2. 1979

3. Tree-line dynamics in Ungava Peninsula, northern Quebec.

4. Holarctic Ecology 2:239-248

5. a. Canada; Index maps NO-18, NO-19; Quebec, B.32

   b. Black spruce, tamarack

   c. Climate/growth (direct relationships, indirect relationships), Climatic change (dendrochronology, proxy data), Treeline studies (climate, growth)

6. The study on treeline dynamics discussed in this paper was undertaken near the Leaf River on the Ungava Peninsula (58 15 N, 72 00 W). The characteristics of the present treeline in continental northern Quebec appear to be related to modern and past ecological conditions. As inferred from the reproductive strategies of black spruce and tamarack from the present treeline populations, major changes during postglacial time in northern Quebec are not only concerned with treeline position, but also with treeline composition. The present treeline involves tamarack and corresponds to its natural seed regeneration limit. Black spruce probably reached its northernmost Holocene latitudes during a warmer period and it then formed the treeline. During the Little Ice Age, fires destroyed large tracks of forest and black spruce krummholz (400, and 250 to 200 yr ago); afterwards, tree species re-established only in protected sites, and exposed sites were not reseeded. At some places, fires did not completely burn the forest cover, and preserved isolated trees and small groves probably became centres for forest re-establishment. Differential forest regeneration and tree age structure suggest that fire and climate are intimately associated in controlling tree population dynamics.

According to fire periods and age structure the tree populations seem to record the same climatic pattern where differential favourable forest growth appeared around 1675, 1725, 1775 to 1820, 1870 to 1880 and 1930 to 1970. Less favourable forest regeneration periods took place around 1700, 1750, 1820 to 1870, 1890 to 1920 and 1970 to the present. These periods seem to match evidence from other dendrochronological studies for the Ungava Peninsula. Extended regeneration between 1775 and 1820 was not observed at all study sites. The period 1800 to 1820 is viewed as a cold one in the dendrochronological curves. The trends in age structures do not emphasize this apparent cold period. Climatic trends during the present century suggest that after the 1920's, summers were warmer in the study area. This is emphasized by vigorous tamarack seedling establishment in forests of the study area between 1930 and 1970. Climate has been significantly colder since the 1960's.

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Payette, S. and Gagnon, R. 1979. Continued

Since approximately 400 BP fire has markedly influenced the landscape near treeline on the Ungava Peninsula. Differential regeneration of forest did occur, and suggests that climatic conditions were selective. Unforested areas and open forests favoured larch seed establishment in suitable sites, and abundant layering in black spruce. The authors were unable to explicitly relate fire characteristics of frequency, distribution and extent to specific climatic conditions, but they suggested that an increase of forest biomass with time in any particular location at the treeline is the main factor of fire ignition whatever the climate in the Ungava Peninsula. Further investigations of this possibility was suggested.

1. **PAYETTE, Serge, Jacques OUZILLEAU and Louise FILION**

2. 1975

3. Zonation des conditions d'enneigement en toundra forestière, Baie d'Hudson, Nouveau-Québec.

4. Canadian Journal of Botany 53:1021-1030

5. a. Canada; Index map NO-18; Quebec; B.32

   b. Black spruce, white spruce

   c. Climate/growth (direct relationships, indirect influences, microclimate, latitude), Treeline studies (climate)

6. Data on snow depth and snow density of various forest-tundra coniferous stands are presented in this paper for a study area near Richmond Gulf (56 20 N, 76 00 W). A latitudinal pattern in snow conditions is observed in the forest-tundra environment, as predicted from the facts that are obtained when this phytogeographical region is subdivided, firstly, into a forested subzone in the southern part and a shrub zone (or krummholz) in the northern part and, secondly, into a maritime ecoclimatic area near Hudson Bay and a continental ecoclimatic area inland. The most snowy coniferous stands are located in the shrub subzone, snow density rises gradually from the taiga to the tundra. The highest values in snow properties are found in the maritime ecoclimatic area. These data suggest the following: 1) maximum snow depth measured in the northern part of the forest-tundra is explained by an increase of barren ground cover and by the presence of more open coniferous stands, which favour snow drifting and snow trapping; 2) the gradual increase in snow density is related to more rigorous climatic conditions; wind exposure is rather important since these sites are more open; and 3) the differences in snow conditions between the ecoclimatic areas show that the maritime environment is more windy; the presence of scattered and erect white spruce in various krummholz formations in that area favours more efficient snow traps than those of krummholz formations located in the continental area. The latter is dominated by prostrate and erect black spruce that is always densely agglomerated. The latitudinal pattern in snow conditions reflects the climatic conditions of the forest-tundra transition zone, and this determines the specific ecological distribution of coniferous stands.

1. PEET, Robert K.

2. 1981

3. Changes in biomass and production during secondary forest succession.

4. IN: D.C. West, H.H. Shugart and D.B. Botkin, Editors, Forest Succession: concepts and application, Springer-Verlag, New York, p 324-338

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree), Climate/growth (indirect influences)

6. Although this article is based on only limited examples directly from boreal forest study areas, the author's review contains concepts and theories of widespread application to boreal and temperate forest ecosystems. One of the most fundamental ways in which forests change during secondary succession is in energy relations. By definition, biomass increases during forest succession from near zero to that found in mature forests. The details of this pattern of increase are not well established.

The simple hypothesis is that biomass increases in a smooth, logistic fashion toward an upper limit fixed by site conditions. Several studies present data that support this hypothesis.

A second hypothesis, which incorporates stand breakup, is that biomass increases to a maximum in late successional stages, only to drop with the development of the climax community. A third hypothesis predicts an initial increase followed by a drop and then a subsequent recovery. This hypothesis implies that instead of a simple dip to an asymptotic climax level, biomass shows a series of damped oscillations around the equilibrium level. Examples of such damped oscillations have been documented for boreal forest types in Finland, Sweden and Alberta. A fourth hypothesis of forest biomass change during secondary succession is that after an initial peak, the quantity of living biomass that can be supported steadily decreases as available nutrients are tied up in dead organic matter. The latter is primarily a phenomenon reported from boreal sites with organic soils.

The author reviewed the several divergent patterns of biomass change during succession and then developed a single conceptual model based on tree population dynamics. The model proposes that the major patterns of biomass change can be understood in terms of time lags in regeneration and of synchrony of mortality. An initial wave of regeneration dominates after disturbance. This is a period of increasing biomass during which tree growth and mortality are the dominant processes. The dense tree

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population is viewed as inhibiting regeneration through resource pre-emption. Failure of regeneration results in an eventual stagnation in biomass accumulation and eventually a drop. Regeneration starts only after natural thinning of the canopy has progressed to the point where resources released by mortality are no longer pre-empted by increased growth of existing trees. Once the even-aged forest structure is lost, peak biomass cannot again be reached without outside disturbance. If for some reason regeneration is not suppressed early in stand development, possibly because of low initial recruitment rates, the biomass drop might not occur.

During succession following forest removal, net primary production increases from zero to some positive value. If biomass lost through tree death and plant shedding is subtracted, the net primary production should again approach zero during the climax or equilibrium stage. This result is implicit in the definition of secondary succession.

The classical interpretation of succession is that successive vegetation stages modify the environment, preparing the way for subsequent stages. The environmental amelioration should allow increased production. Certainly the increase of net production to an asymptote at climax is widely accepted for certain cases of classical xerarch succession. For secondary forest succession, however, only a few cases of asymptotic increase have been reported, and these only with limited data. An alternative hypothesis is that a finite quantity of resources is available for plant growth each year, with the result that after an initial but brief recovery period, production is independent of stand age.

The constant production concept applies more readily to gross production than to net production, at least if light or carbon is the limiting resource. It can be argued that as the quantity of living biomass in the forest increases, a steady decrease in net production should be expected because increasing amounts of respiration must be subtracted from constant gross production.

One hypothesis suggests that production drops more during the later portion of forest development than can be accounted for by increased respiration. Rodin and Bazilevich (1967) cite several examples of major drops in forest production with age. They refer to forests of pine and spruce on high quality sites in the U.S.S.R. subarctic zone, where both species reach peak production between 40 and 50 yr, only to drop to levels of around 25% of their maxima at age 110 yr. The drop in production during the latter phases of succession is variously attributed to developing forest structure, changing species composition, and changing nutrient availability. The question of whether successional communities are more productive than climax ones is still unanswered for most successional seres in the world.

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Species-independent aspects of stand development can also be used to explain a late succession drop in production. The dynamics of most even-aged, post-disturbance forests are dominatd by a thinning process; as dominant individuals in the initially dense population of trees grow, many smaller trees die. Over the short term, stand development can be viewed simply as decreasing tree density and increasing tree size.

An additional aspect of even-aged stand development that could limit production is tree senescence. As the original trees age, they lose their capacity for high levels of production, thus lowering stand production until such time as they are replaced by young, vigorous trees.

The potential role of nutrient availability in biomass accumulation cannot be ignored. Nutrient losses can be hypothesized to have a negative feedback on primary production. Early in succession, production should be relatively high due to a large pool of available nutrients. After this pool has been exhausted, production should be limited by nutrient inputs. When biomass (both living and dead) has reached a stable level and nutrients are not being sequestered in new biomass, production should be less limited by nutrients. Changes in available nutrient pools thus have the potential to partially counteract the tendency for a nigh peak in the middle stages of stand development. The author stressed that more information is needed before the importance of nutrient limitation as a negative feedback can be adequately evaluated.

Observed changes in forest production during succession can partially be explained in terms of the time lag model applied by the author to changes in biomass. After disturbance, production should increase steadily to a plateau dictated by site conditions. The rate at which this plateau is approached will depend on the initial rate of tree establishment. Stands initially densely stocked will plateau in only a few years, whereas on extreme sites with low establishment rates, production will only slowly increase to an asymptote. On favourable sites, after the initial plateau, net production should drop at least gradually as nonphotosynthetic biomass builds up. The rate of drop will depend on tree density and tree senescence. During this period of thinning, regeneration will be minimal. When thinning reaches the point where existing trees can no longer successfully pre-empt resources released by tree mortality, regeneration will resume. If the loss of canopy trees were to occur over a relatively short period, the replacement of old, senescent trees by young, vigorous saplings could result in a marked increase in production and a subsequent slow drop. In contrast, if mortality were gradual, the second increase might never occur.

In summary, the degree of time lag or length of interruption in regeneration will have a major impact on stand biomass and production. Where the time lag is minor, a single peak in biomass with a subsequent drop to an asymptote is typical. Where lack of a time lag is coupled

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with slow initial regeneration, a simple asymptotic increase in biomass and production can be found. However, where the time lag in regeneration is marked, strong but damping oscillations can be expected in biomass and production. The proposed time lag model does not incorporate all of the important factors influencing biomass and production during secondary succession. For example, the concept of decreasing production during succession based on changes in the geometry of the dominant tree species is probably important, yet it is not incorporated. Nutrient limitations are also important in many systems.

1. PERALA, Donald A.

2. 1973

3. Stand equations for estimating aerial biomass, net productivity, and stem survival of young aspen suckers on good sites.

4. Canadian Journal of Forest Research 3:288-292

5. a. Minnesota

   b. Aspen

   c. Biomass (tree)

6. This study developed stand equations for estimating aerial biomass, net productivity, and stem survival in young trembling aspen growing on good to excellent sites in north-central Minnesota. Aerial biomass was defined as the total oven dry weight of all above-ground components of living aspen, except leaves, expressed in kilograms per hectare. Net productivity was defined as the rate of aspen dry matter production minus mortality expressed as kilograms per hectare per year.

The author developed stand biomass equations as well as equations for stand net productivity and stem survival. It was concluded that net productivity is much more easily modelled than stem survival. Addition of productivity class variables such as site index or some measure of clone characteristics undoubtedly would account for additional variation in net productivity between aspen stands. Due to the restricted range of the available productivity data with respect to site index, the net productivity equations presented by the author should be limited in application only to the best aspen sites (site index 21 m at 50 years and above).

Optimum rotation age for maximum total fiber is determined as the age where mean annual increment (M.A.I.) and periodic annual increment (P.A.I.) intersect. The equations developed in this study indicated that the optimum rotation age for wood and bark was about 25 yr for the upper density class, and about 2 yr later for the wood component. It is likely that relatively few natural aspen stands exist where M.A.I. culminates earlier than 20 yr. For example, the aspen stand reported by Einspahr and Benson (1968) with 42,000 kg/ha of wood alone at age 15 and the stand reported by Bella and Jarvis (1967) with 36,000 kg/ha of wood and bark at age 13 fall within the limits of the data range of this study. Previous biomass measurements of sucker stands in northern Minnesota had indicated that maximum productivity had not been reached by age 12.

In summary, early culmination of mean annual net productivity in natural aspen stands appears to be encouraged by high numbers of suckers, high initial accumulation of biomass, and high site index - all of which are dependent on clonal characteristics.

1. PERSSON, Hans

2. 1979

3. Fine-root production, mortality and decomposition in forest ecosystems.

4. Vegetatio 41:101-109

5. a. Sweden

   b. Scots pine

   c. Biomass (tree, shrub/herb)

6. The temporal variations in fine root growth (less than 2 mm diameter), mortality and decomposition were studied in two stands of Scots pine, 18 and 120 yr old, respectively, in 1974. The study area was located in central Sweden at 60 46 N, 16 39 E. Using sequential soil core sampling, the averages of the total root biomass in the two study stands were estimated as follows:

Root biomass components, dry weight

	18-yr stand				120-yr stand			
	1*	2	3	4	1*	2	3	4
Betula sp.	0.2	0.0	0.6	0.0	0.1	-	0.1	-
Pinus sylvestris	26.1	67.6	49.8	164.7	122.5	64.2	313.1	116.6
Empetrum nigrum	0.6	-	0.6	-	1.8	2.8	0.4	0.4
Calluna vulgaris	50.2	17.6	102.9	54.5	61.8	15.0	158.0	58.2
Vaccinium myrtillus	0.1	-	0.3	-	0.0	0.0	0.0	0.0
V. vitis-idaea	48.7	40.0	48.7	40.0	157.9	32.0	157.9	32.0
Deschampsia flexuosa	0.0	-	0.0	-	-	-	-	-

1* Living fine root biomass (g/m^2)
2 Stand fine root dead material (g/m^2)
3 Total living root biomass (g/m^2)
4 Total dead root material (g/m^2)

To estimate the amount of new root growth, root-free cores were inserted into the soil in the fall of 1974 and the ingrowth of new roots into these cores on successive sampling occasions was measured as follows:

Root ingrowth (g/m^2 dry weight) from 1974 to 1975-76 and 1976-77

	18-yr stand		120-yr stand	
	1975-76	1976-77	1975-76	1976-77
Pinus sylvestris	139	22	128	202
Calluna vulgaris	26	11	36	53
Vaccinium vitis-idaea	26	16	5	27

Continued ...

Persson, H. 1979. Continued

The results of this study indicated that the annual supply of organic matter to the soil from fine root components exceeded in many cases that which is produced and supplied to the soil from litterfall. The largest supply of soil organic matter from the tree component seems to go to the mineral soil, whereas that of the superficially distributed dwarf shrubs goes to the F/H layer. A large amount of the total tree biomass is accumulated in the form of coarse roots as the forest stand ages, but annual root production is only about 5% of that which takes place in fine roots.

The results indicate that fine root production and below-ground turnover exceed levels conventionally expected in forest ecosystems. In future ecosystem studies, there is a need for better estimates of the rates of change in biomass of root systems, rather than solely structural descriptions of them.

1. PETERSON, E.B., Y.H. CHAN and J.B. CRAGG

2. 1970

3. Aboveground standing crop, leaf area, and caloric value in an aspen clone near Calgary, Alberta.

4. Canadian Journal of Botany 48:1459-1469

5. a. Canada; Index map NM-11; Alberta; B.19c

   b. Aspen

   c. Biomass (tree)

6. A 1967 aboveground harvest of 49 ramets of aspen (Populus tremuloides), aged from 66 to 89 years, at an altitude of 1,430 m in Alberta revealed a leaf area index of 1.8 (one side of foliage) and a clone standing crop of 77.11 t/ha (oven-dry weight) with an energy equivalent of 3,630 X 10^6 gram calories/ha. This standing crop estimate fell within the range of 58 to 290 t/ha reported elsewhere for aspen. The amount of aspen foliage and branch wood, as a percentage of total aboveground standing crop, increased from the bottom to the top of a slope gradient within the 0.02 hectare sample plot, indicating that topographic position exerted a phenotypic expression on production structure within the clone. Topographic position did not have a significant influence on the applicability of the two most reliable independant variables [(i) diameter at breast height squared X tree height, (ii) diameter of trunk at crown base] for prediction of the total aboveground weight and component weights of aspen ramets.

A noteworthy feature of the production structure of the clone described by the authors is that, despite the low standing crop value and the apparently low site productivity, the fully closed portion of the stand had a standing crop density of 1.16 kg/m^2, which is comparable to that found in other forests that are taller and much more productive. This supports the contention by other researchers that standing crop density is almost independent of stand height in forests and that fully closed forests tend to have a standing crop density of 1.0 to 1.5 kg/m^2.

1. POHTILA, Eljas

2. 1980

3. Climatic fluctuations and forestry in Lapland.

4. Holarctic Ecology 3:91-98

5. a. Finland

   b. Scots pine

   c. Climate (air masses, precipitation, temperature), Climate/growth (latitude), Climatic change (hypotheses), Climatic variations (temporal), Growing season (degree-day totals), Treeline studies (climate)

6. This is a report of the author's work conducted at the Finnish Forest Research Institute, Rovaniemi Research Station, Eteläranta 55, SF-96300 Rovaniemi 30, Finland. Climatic fluctuation is considered to be a serious problem for forestry in Lapland. For example, in 1901-02 there was serious damage to Scots pine (Pinus sylvestris). The summer of 1901 was exceptionally warm and the following year's leader shoots grew for a longer time than usual. As the summer of 1902 was late and very cool, the shoots did not have enough time to lignify before the onset of winter and were damaged by frost. Other climatically related damages to pine and birch were recorded in Lapland in the 1960's.

The author's review of climatic problems associated with reforestation begins with an account of temperature controls over seed production in Scots pine, but most of the analyses deal with forest growth for which yearly deviations from the long-term average may reach 40% in Lapland. The 5 to 10 year mean commonly used in growth studies may deviate by more than 20% from the long-term average. It is not absolutely clear which portion of this growth variation is caused by climate. Tree growth-climate interactions are known to be very complicated and the size, age and silvicultural treatments of the stands are also significant influences upon growth.

Historically, Lapland studies have stressed the significance of temperature as an influence upon growth, but the author found the index of atmospheric circulation over the northern hemisphere to be the most effective climatic parameter to explain the growth variation of Scots pine. Zonal circulation has been defined and recorded by Dzerdzeevskii and Sergin (1972) in Nordia 2:427-453 in an article entitled "A procedure for studying climatic fluctuations on different time scales". This parameter is based on surface synoptic and high-level maps of the entire northern hemisphere. The positions of basic isobar patterns and trajectories of centres of high pressure in four directions are taken as

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indices. The zonal circulation is the so-called "strong" type of circulation, under which the circumpolar vortex is contracted and the oscillation of the westerly winds that sweep around the North Pole is confined within a narrow range of latitudes. The opposite extreme is the meridional circulation pattern.

For the period from 1910 to 1975, the coefficient of correlation between annual forest growth and annual zonal circulation ranged from 0.5 to 0.7. In the same period, the coefficient between forest growth and the temperature sum of the growing season was found to be only 0.3 and 0.4, based on data from the Sodankylä climate station (67 22 N, 26 39 E). The highest correlation coefficient between zonal circulation and growth index was obtained using a lag time of two years. The range of climatic factors tested included temperature sum, precipitation, cloudiness, atmospheric pressure, zonal circulation, and sunspots.

The author suggested two ways to moderate the effects of climate fluctuation: (1) in forest management, a risk margin should be maintained to allow for climatic variations; and (2) the nature and causal relationships of the fluctuation should be clarified because if the fluctuations are not entirely random by nature then forestry can be planned to match any regularity in the fluctuation. Although many cycles have been described from studies of weather records, tree rings, glacial clay sediments, or heavy stable isotopes concentrated in the polar ice sheet, many of the cycles that were earlier considered to be real have proven to be statistical artifacts. The author de-emphasizes the importance of "cycle hunting" except when the search is based on exact and complete weather records and on numerical modelling of causal relationships.

There is not yet any complete, generally accepted explanation for climatic fluctuations but there is an abundance of theories. Budyko (1974) has convincingly demonstrated that volcanic eruptions may decrease air temperature over vast areas, and many of the exceptionally cold growing seasons in Lapland (1902, 1892, 1893, 1837, 1832 and 1810) have coincided with famous eruptions.

Some climatic fluctuation is due to extraterrestrial factors. Just as the moon produces tides in the oceans it also produces tides in the atmosphere. An increase in the gravitation of the moon moves air masses in both hemispheres towards the equator. Most of the gravitational cycles of the moon, lasting from two to nine years, proved to be statistically related to tree-ring series documented from the northern treeline by Sirén and Hari (1971) for the period from 1181 to 1960 A.D. These "Saros cycles" have also been found in weather records.

The possible role of solar activity in climatic fluctuation has been studied for about 100 yr and is still a very controversial topic. The author's studies indicated that regeneration years for Scots pine at the

Continued ...

Pohtila, E. 1980. Continued

northern treeline frequently coincided with the maximum of the 11-year sunspot cycle, with some of the most important regeneration years being 1575, 1650, 1761, 1851, 1927, 1938, 1940, 1947, 1961 and 1972. On the other hand, the most severe failures of agricultural crops in Finland since 1530 seem to have coincided with the minima of the 11-year sunspot cycle.

According to Sirén (1961) there is a clear periodicity in the radial growth of Scots pine at the northern treeline and the growth index corresponded closely to sunspot data smoothed out using a 33-year moving average. He found that the factor most closely related to radial growth was the mean temperature for June-August adjusted for various parameters, especially the mean temperature in July of the preceding summer. However, Pohtila stressed that mechanisms of tree growth are very complicated and statistical correlations are not always based on real cause and effect relationships. For example, Fraser-Smith (1978) suggested that solar activity may also influence the growth of trees through the earth's magnetic activity independently of climate.

The author examined relationships between sunspots and temperature and precipitation for the period from 1910 to 1975. On an average, temperature sums increase when the number of sunspots increases; an inverse regression was found between precipitation and the number of sunspots. Interestingly, zonal circulation over the northern hemisphere, which correlated closely with a tree growth index, had no clear statistical connection with the number of sunspots. Zonal circulation correlated significantly with only precipitation, over and above its correlation with growth index.

When sunspot activity was analysed in relation to various parts of the growing season, it appeared that the possible effects of solar activity were most distinct in spring and autumn when the earth's heliographic latitude and magnetic activity reach their maxima.

The cyclical variation in the number of sunspots has been explained and predicted by means of the gravitation of the planets on the sun and these predictions are statistically quite accurate. If the correlations between solar activity and climate are real and if the sunspot predictions are accurate, Lapland's summer temperatures will become cooler until 2000 A.D. and annual precipitation will increase. The author stressed, however, that sheer periodicity of fluctuations without any physical explanation does not offer a firm basis for prediction purposes. The main point that can be stressed from the author's studies to date is that the zonal circulation explained the growth variation of Scots pine better than any other local weather parameter.

1. POLLARD, D.F.W.

2. 1971

3. Mortality and annual changes in distribution of above-ground biomass in an aspen sucker stand.

4. Canadian Journal of Forest Research 1:262-266

5. a. Canada; Index map NL-17; Ontario

   b. Aspen

   c. Biomass (tree)

6. This investigation sought estimates on the distribution of above-ground biomass and mortality losses in different diameter classes after 4, 5, 6, and 7 yr development of a natural aspen stand. The study area was at Chalk River, Ontario (46 00 N, 77 24 W), about 100 km south of the southern edge of the boreal forest in Ontario.

Biomass of stems and branches increased from 17,000 kg/ha in the 4th yr to 34,000 kg/ha in the 7th yr of development of an aspen sucker stand. The bulk of the biomass was distributed in the middle and upper diameter classes of shoots; net annual increases only occurred in the upper classes. About 80% of shoots dying in the 3rd yr of study were less than 2 cm dbh; the biomass lost in these amounted to 200 kg/ha or less each year. The remaining 20% mortality occurred in the 7th yr among the shoots 2 to 5 cm dbh infected with **Diplodia tumefaciens**. Biomass lost in these larger shoots amounted to 4,900 kg/ha; this was close to the discrepancy between net production (stems and branches) in the 7th yr (2,600 kg/ha/yr) and net production in the 5th and 6th yr (about 7,000 kg/ha/yr). Results suggest that although high rates of net annual production are obtainable in short rotations, the mean annual production is strongly influenced by disease because of insufficient time for enhanced growth of survivors. The latter circumstance implies that aspen production in very short rotations may be more dependent on environmental vagaries than in conventional rotations.

The distribution of biomass among dbh classes of aspen suckers was as follows:

Year (fall)	Dbh classes (cm) 0-1	1-2	2-3	3-4	4-5	5-6	6-7	Total
	Biomass (kg/ha)							
1967	300	2,500	7,000	6,700	700	0	0	17,200
1968	300	1,900	6,100	10,300	5,500	0	0	24,100
1969	200	1,600	5,100	10,000	11,900	2,800	0	31,600
1970	100	1,400	4,100	7,500	12,100	7,100	1,900	34,200

1. POLLARD, D.F.W.

2. 1972

3. Above-ground dry matter production in three stands of trembling aspen.

4. Canadian Journal of Forest Research 2:27-33

5. a. Canada; Index map ML-17; Ontario

   b. Aspen

   c. Biomass (tree), Climate/growth (indirect influences)

6. Above-ground biomass, annual production and leaf area index were estimated for several years in aspen stands aged 6, 15 and 52 yr in 1968. The study site was located at the Petawawa Forest Experiment Station, approximately 100 km south of the southern edge of boreal forest section B.7 in Ontario. Based on regressions of dry weight on stem diameter, estimated biomass of stems and branches for 1968 were 21,500 kg/ha in the juvenile stand, 51,200 kg/ha in the intermediate stand, and 91,800 kg/ha in the mature stand. Net annual above-ground production of stems and branches for these stands in 1968 was 6,900, 7,000 and 1,340 kg/ha/yr, respectively. In 1969, foliage amounted to 2,600, 2,600 and 1,500 kg/ha, providing leaf area indices of 2.4, 2.9 and 1.6 for the three stands, respectively. Net assimilation rates were roughly 20, 17 and 9 g/m^2/week in the three stands.

In the examples studied, annual production of the youngest aspen stand was as high as that of the 15-yr old stand, and several times greater than observed in the oldest stand. It is apparent that unusually high production can occur early in stand development. The root systems of aspen sucker stands are likely to be well developed early in the life of the trees, because all stems originate from existing roots. Thus in this type of community, production may reach a maximum coincident with maximum leaf area index and remain high until net photosynthesis or leaf area index begin to decline.

In conclusion, regenerating stands of aspen appear to be capable of attaining maximum productivity a few years after initiation. The capacity for early production probably results more from the rapid development of a canopy and early attainment of maximum leaf area index than from especially efficient photosynthesis; the presence of an extensive root system at the time of stand regeneration may explain the speed of canopy development. Low production in old stands is probably associated both with reduction in leaf area index when development of crowns can no longer compensate for thinnings, and with increasing demands for water, nutrients and photosynthates, as reflected in low net assimilation rates.

1. POWELL, John M.

2. 1981

3. Impact of climatic variation on boreal forest biomass production.

4. IN: C.R. Harington, Editor, Climatic Change in Canada - 2, National Museum of Natural Sciences Project on Climatic Change in Canada during the past 20,000 years. National Museums of Canada, National Museum of Natural Sciences, Ottawa. Syllogeus No. 33. p. 189-194

5. a. Canada; Index maps (all in boreal zone); all boreal forest sections in Canada

   b. Nil

   c. Climatic change (proxy data), Climatic variation (regional, temporal, temperature)

6. The author indicated that little is known about the effect of climatic factors on biomass and how climatic fluctuations influence forest growth and yield. The rate of biomass renewal under a wide range of environmental, site and growing stock conditions is unknown. It is known, however, that present forests and their associated vegetation did not evolve under constant or uniform climatic conditions. Different regions of our forests are subjected to widely contrasting temperature and precipitation regimes. Weather patterns are highly variable from year to year. Today's forests reflect past climates. Their origins in time and space, growth rates, species composition, longevity and total biomass are largely dictated by past and present climates.

There is clearly a need for more information on climatic fluctuations that have occurred in the boreal forest zone. However, there are few long-term weather stations in this zone, and none with a record of 100 yr. Proxy data, drawn from biological, chemical and physical characteristics that respond to climate, indicate that important climatic fluctuations occurred in the past, and that the position of the boreal forest zone and northern treeline has shifted also. The boreal forest presently occupies a zone with a summer temperature range of only 2° C. Any long-term cooling, even if only 0.5° C, would adversely affect this zone and its productivity. Therefore, information is needed in two specific areas: (1) the impact of climate on forest biomass production; and (2) past climates in the boreal forest region.

The author described a study now in progress. The two overall objectives of the study are to determine: (1) the extent and degree of past short-term and long-term climatic variation in selected regions of the boreal forest to assess impact of climatic change upon tree and forest growth; and (2) quantitative and qualitative relationships between key climatic parameters/climatic variations, and measures of forest biomass growth and production in selected regions of the boreal forest.

Continued ...

Powell, J.M. 1981. Continued

Tree-ring chronologies have long been used to gather information on past climates. This type of analysis can also help identify various climatic factors that have played a major role in forest production. Ring-width and density profiles can also provide year-to-year biomass data. Researchers in British Columbia have shown that on an altitudinal transect in the Columbia River valley of southeastern British Columbia, temperature/tree-ring correlations were more significant at higher elevations, whereas precipitation/tree-ring correlations were more significant at lower elevations. The author suggested that a similar relationship may occur on a latitudinal transect of the boreal forest zone. If this can be shown, it would be relevant to any dendroclimatological studies undertaken in the Interior Plains and elsewhere in North America.

1. POWELL, J.M. and D.C. MacIVER

2. 1976

3. Summer climate of the Hinton-Edson area, west-central Alberta, 1961-1970.

4. Environment Canada, Canadian Forestry Service, Northern Forest Research Centre, Edmonton. Information Report NOR-X-149. 43 p

5. a. Canada; Index map NN-11; Alberta; B.19a, B.19c

   b. Nil

   c. Climate (precipitation, temperature), Climatic variation (regional, temperature, precipitation), Growing season (length)

6. The summer climate (May to September) was described for an area of west-central Alberta between 52 50 N and 54 15 N and 115 30 W and 119 05 W. The analysis was based on daily temperature and precipitation data for the decade 1961 to 1970 from 20 stations. Seasonal and monthly values for the months of May to September are given for mean daily temperature, total precipitation, frequency of days with a mean temperature above -2.2° C, and water deficiency assuming a spring storage level of 100 mm. These variables, along with latitude, longitude, and elevations were used as input for a factor analysis. The factor scores were then used in a hierarchical grouping procedure, followed by discriminant analysis to give statistically stable groups. The most statistically significant variables were also used to aid in the positioning of climatic boundaries. Six macroclimate groupings were represented in the area; the mean and range of the 15 most important discriminating variables were given for each of these groups.

The statistically significant variables in order of decreasing significance were: frequency of days with a mean temperature above -2.2° C in May; mean daily temperature in May; June days with a mean temperature above -2.2° C; longitude; elevation; July mean daily temperature; July total precipitation; August total precipitation; August moisture deficiency; latitude; May total precipitation; June moisture deficiency; September precipitation; July frequency of days with a mean temperature above -2.2° C, and August frequency of days with a mean temperature above -2.2° C.

The five month summer period is particularly important for forest growth because it includes the whole of the growing season. Some of the main features of this summer period in the study area are summarized below.

Over the five month season the warmest stations are Jasper and Whitecourt, both located in a major river valley. The coolest stations are at the higher elevations in the foothills or front ranges of the

Continued ...

Powell, J.M. and D.C. MacIver. 1976. Continued

Rocky Mountains. Most of the study area has summer seasonal temperatures between 8 and 12°C.

Seasonal total precipitation for May to September varies from a low of 200 mm at Jasper to over 465 mm at some higher elevations. Jasper appears to be in a marked rain shadow location. July is the wettest month with most of the study area receiving 100 to 130 mm of precipitation.

Most of the study area has over 130 days with mean temperatures above -2.2° C. At higher elevations the number of days decreases, to 100 or less, while some stations on the northern edge of the study area and in major river valleys have totals of 145 days with mean temperatures above -2.2° C.

Seasonal water deficiency total, assuming a spring storage level of 100 mm, is highest at Jasper with 150 mm deficit, followed by Edson with 137 mm deficit. The other seven weather stations that recorded seasonal water deficiencies had deficits in the range of 8 to 61 mm. None of the stations experienced a water deficiency in May. Four stations, those having the greatest seasonal deficiency, show a deficiency in June. Only Jasper has a monthly water deficiency of 50 mm or more, in July and August.

1. POWELL, J.M. and D.C. MacIVER

2. 1978

3. Maps of selected climatic parameters for the prairie provinces, May to September, 1961-1970.

4. Fisheries and Environment Canada, Canadian Forestry Service, Northern Forest Research Centre, Edmonton, Information Report NOR-X-206. 31 p

5. a. Canada: Index maps (all in Alberta, Manitoba and Saskatchewan); All boreal forest sections in Alberta, Manitoba and Saskatchewan

   b. Nil

   c. Climate (precipitation, temperature), Climatic variation (regional), Growing season (length, frosts)

6. For the period from 1961 to 1970, this report contains 23 maps of mean daily temperature (° C), mean precipitation (mm), mean number of days with a minimum temperature of -2.2° C or below, and mean water deficiency (mm). Water deficiency values were calculated using Thornthwaite's water balance technique adjusted for a 7-month period from April to October, assuming a soil moisture storage of 100 mm per year by the end of March. The -2.2° C (28° F) minimum temperature was selected as a parameter because values below this point are considered to be killing frosts for most sensitive vegetation. Separate maps are presented for each of May, June, July, August and September and for the entire summer season (May to September inclusive) for each of the above parameters except for mean water deficiency in May; during May only one station out of 360 in the data base showed a small water deficiency so no map was presented for this parameter during May.

The 360 stations used in the study included all stations in the forested areas of the prairie provinces with an adequate record during the same period (1961-1970). It was necessary to generate missing daily values for many of the forest-fire weather stations, especially in May and September, to provide complete sets of data to estimate mean values for the study period. The report is an extension of the authors' earlier work (Powell and MacIver 1977) on a factorial summer climatic classification of the forested parts of the prairie provinces. The 1978 report incorporates data from 56 additional stations mainly in the agricultural parts of the prairie provinces and from Churchill, Manitoba. The original maps of summer climatological zones did not provide information about the climatic variables used in the analyses; the seasonal and monthly maps published in this report were designed to make this information available.

The mapped information is too detailed to annotate here, but some of the more notable features described by the authors are summarized below.

Continued ...

Powell, J.M. and D.C. MacIver. 1978. Continued

The isolines for mean May temperature tend to form almost uniform bands from northwest to southeast in the prairie provinces. Isotherm bands are also found parallel to the mountains. Certain local uplands, such as the Swan Hills and Birch Mountains in Alberta and Riding Mountain in Manitoba, have noticeably cooler temperatures than surrounding areas. For the entire growing season (May to September inclusive), most of the boreal forest within Alberta has mean daily temperature values between 11 and 12° C.

The seasonal (May to September) precipitation totals show values from 150 mm on the south shores of Great Slave Lake to 483 mm at Emo, Ontario. In Alberta, there are several areas with total seasonal precipitation over 450 mm and the Swan Hills and Marten Mountain-Stoney Mountain areas in Alberta have May-September precipitation totals over 400 mm. Much of the boreal forest zone receives less than 300 mm from May to September, although totals are less (around 200 mm) in the northern part of the zone near the Alberta-Northwest Territories border.

In general, May is the driest of the five summer months in the prairie provinces and monthly precipitation totals reach their maxima in June and July.

The seasonal map of days with a minimum temperature of -2.2° C or below shows the greatest range in the Rocky Mountains and foothills area of Alberta, with frequencies ranging from less than 10 days to over 35 days for the May-September period. Most northern stations in the prairie provinces have frequencies over 15 days for this five-month period. The isolines for 6, 10, 15, 20 and 25 days during May with a minimum temperature of -2.2° C or below generally trend from northwest to southeast within the prairie provinces. The topographic effect of the Rocky Mountains is shown by the very rapid gradients in short distances for the number of days in May with minimum temperature of -2.2° C or below. By June, only a few areas in the Rocky Mountains have greater than 5 days with a minimum temperature of -2.2° C or below. In August a few stations in the Rocky Mountains or high foothills have more than one day with a killing frost, with the highest frequencies at Muskeg Ranger Station and at Adams Creek Lookout.

Several stations close to large water bodies such as Lake Athabasca, Great Slave Lake and Lake Winnipeg retain relatively low frequencies of killing frosts through September.

In the forested and fringe agricultural zone, some areas have no May to September water deficiency. These areas occur mainly in the Rocky Mountains (excluding the major river valley locations) and foothills, with a few stations also in the area south of Fort McMurray. Highest water deficiencies for May to September (over 150 mm) occur in northern Alberta and adjacent Northwest Territories.

Continued ...

The authors point out that climatic maps that use stations in mountain valley locations show below-average temperature values for these regions unless topography is taken into account. Even away from mountains, stations in deep valleys receive less precipitation than the neighbouring plains and hilly areas. The authors stress that the maps in this report represent mean values. Many of the stations used were situated in valleys, on lake shores, or on hill-tops in the case of fire weather lookouts. Caution is therefore needed in identifying them as representative of the surrounding area. In future climatic work, greater emphasis could be given to topographic allowances when isolines are drawn in hilly terrain; however, this would require a larger map scale and more information than is presently available to quantitatively describe topographically induced variations in temperature and precipitation.

For calculation of seasonal or annual water deficit, the assumed 100 mm of soil moisture recharge in March is an average value for a loam soil with a cereal cover with moderate root development. For a loam soil with a mature forest cover a storage capacity of 300 mm is generally assumed, and if the soil is a sand or clay or is shallow over bedrock then other storage capacities, perhaps as low as 25 mm, should be used in calculation of water deficit. The authors also stress that if an area has a high natural water table the calculati . of a water deficit based on climatic data may be meaningless. It is also known that forest vegetation can store an appreciable quantity of water; this is in addition to the water stored in the soil and is particularly effective in areas of shallow soils. These circumstances should be considered in any detailed water balance studies in forested areas.

1. **RENBERG, Ingemar and Ulf SEGERSTRÖM**

2. 1981

3. Applications of varved lake sediments in palaeoenvironmental studies.

4. Wahlenbergia 7:125-133

5. a. Northern hemisphere

   b. Mil

   c. Climatic change (proxy data)

6. Varved lake sediments in the temperate zone of the northern hemisphere provide excellent possibilities for palaeoenvironmental investigations. This paper briefly describes the nature of varved lake sediments and gives some examples of their various applications.

A large part of our present knowledge of climatic history is derived from investigations of plant and animal remains preserved in peat and lake sediment deposits. A reliable, quantitative, palaeoecological methodology, based on varved lake sediments, provides a better possibility of drawing conclusions about the changes which have occurred in the biocoenosis in the past, and hence about the climatic changes. Pollen influx values, for example, provide the prerequisite conditions for documenting quantitative changes in plant communities and in the pollen production of various taxa.

The prevailing climate sets its stamp on a lake sediment in other ways too, whereby the continued study of varved lake sediments should become an important source of information for the investigation of past climates. Such attributes of an individual varve such as content of mineral grains and their spatial distribution, the organic matter content, the varve thickness, and the chemical state of iron are both directly and indirectly determined by the macroclimate.

1. **RENCZ, A.**

2. 1976

3. The level and distribution of biomass and nutrients in a subarctic lichen woodland.

4. McGill University, Montreal. M.Sc. Thesis. 56 p

5. a. Canada; Index map NN-19; Quebec; B.13a

   b. Black spruce

   c. Biomass (tree, shrub/herb, moss/lichen)

6. This study quantified the important structural aspects of a lichen woodland. The study area was located near Schefferville, Quebec. These structural characters are all interrelated and are linked to the limited nutrient supply. The distribution of lichen woodlands does not appear to be correlated to moisture as they extend from the humid zone in Canada's northeast to the dry subhumid zone of Canada's northwest. However, the conditions of low soil temperatures and moist soils are considered important factors in lichen woodland development. Although temperatures in the lichen mat may reach 50° C, the energy is not transmitted to the soil horizon. These conditions restrict the plant roots to the upper soil horizons. The lichen woodlands are commonly burned. An estimated 55% of the land near the study area had been burned in the last 25 years.

The following biomass estimates were obtained for the study area:

	Biomass (kg/ha)
Total aboveground components	35,590
Trees	18,740
Shrubs and grasses	5,100
Lichens and mosses	9,750
Total belowground components	9,150
Tree roots	5,970
Shrub roots	3,280
Total biomass	42,740

1. RITCHIE J.C. and F.K. HARE

2. 1971

3. Late-Quaternary vegetation and climate near the arctic tree line of northwestern North America.

4. Quaternary Research 1:331-342

5. a. Canada, Alaska; Index map NR/7/8/9; District of Mackenzie; B.32

   b. Mil

   c. Climatic change (hypotheses, proxy data), Treeline studies (climate)

6. Earlier studies in Alaska and northwest Canada have shown inconsistent evidence for the expected northward extension of the Arctic treeline during the Hypsithermal Interval. Only megafossil evidence has supported this suggestion: the palynological findings have been inconclusive. The authors noted that there is presently a lack of definition of the factors which control the limits of the major northern vegetation zones. It is highly probable that the northern limits of forest growth and individual tree growth are thermally determined. It has been proposed that the cumulative summer warmth, measured by degree days above 50° F, is the operative factor at the northern limit of tree growth. Warm season accumulated temperatures are closely related to net radiation for the same period, implying that energy supply is the critical factor.

It was shown by Bryson (1966) that a major airstream boundary within the atmospheric circulation, the arctic front, is today closely linked in summer with the arctic treeline. North of this front, the prevailing airstreams come from the permanent pack-ice of the Arctic Ocean, and are cold. South of the front much warmer and moister air from the North Pacific dominates. The present day July arctic front is located, in the median, about 300 km south of the treeline in most areas, but very close to treeline over Alaska and west of the Urals. On this basis, the tundra and forest-tundra can be considered as vegetation types typical of areas dominated by arctic airstreams in July. Closed-crown boreal forest lies within pacific airstreams in this month in North America, and within warm continental air over Siberia. The authors suggest as a working hypothesis that similar arrangements pertained during the Holocene.

The extraordinary Holocene contrast between the warm Alaska-Mackenzie climate and the cooler climate of the Hudson Bay area has persisted to the present day, when warm epochs in the western Bering Sea area tend to accompany cold epochs in eastern North America, because of the westerlies involved. It is clear that the amplitude of the western ridge - eastern trough pattern of the arctic front was much higher in 8000 B.P. than it

Continued ...

is today in July. The paradox of flourishing spruce forest along the arctic coast of the Mackenzie District while shrinking glacial ice lay over eastern Keewatin is perfectly consistent with what is known of the dynamics of the westerlies.

The authors make two final comments on their proposed locations of the arctic front and treeline. One is that it calls for a relatively warm summer on the arctic coast plain of Alaska. A spruce phase on that plain, not so far substantiated, is highly probable, unless the Brooks Range slowed down access until the subsequent cooling of the summers. The second point concerns the western coastal tundra of Alaska and the Aleutians. A northward displacement of the arctic front is consistent with a more pronounced onshore flow of cool cloudy maritime polar air from the Bering Sea. If anything, the coastal tundra of this period may hence have been slightly more extensive than today. This argument may account for the conclusion of McCulloch and Hopkins (1966) that the early postglacial warm period in the Kutzebue Sound - Seward Peninsula area terminated about 8000 B.P. If the arctic front in July did in fact move out into the Beaufort Sea during part of the period 8500 to 5500 B.P., as is quite probable, a substantial decrease in summer sea-ice along this flank of the Arctic Ocean should have occurred, and may perhaps be detectable in the offshore sedimentary record.

1. **BOBOCK, Alan**

2. 1979

3. The "Little Ice Age": northern hemisphere average observations and model calculations.

4. Science 206:1402-1404

5. a. Northern hemisphere

   b. Nil

   c. Climatic change (hypotheses), Climatic variation (temporal)

6. In this paper numerical energy balance climate model calculations of the average surface temperature of the northern hemisphere for the past 400 yr are compared with a new reconstruction of the past climate. Volcanic dust may have been an important cause of climatic fluctuations over the past 400 yr. Except for the warm period in the first half of the 1800's the computed volcano curve quite closely matches the weather observations curve.

The hypothesis of sunspot-related solar constant changes is not supported. Thus, the hypothesis that the Little Ice Age is related to the Maunder sunspot minimum through variations in the solar constant is not supported. This result does not rule out the changes in the solar constant as causes of climatic change, but if there is a relation, these changes must either be related to some yet to be discovered index other than sunspots or to sunspots in some very complex way.

Carbon dioxide produced by fossil-fuel burning does not seem to have had a significant effect on climatic change as yet. With it the results are slightly better for the entire record and slightly worse for the most recent portion. This conclusion should be qualified because there may be compensating anthropogenic influences such as aerosols, and the model tends to underemphasize the CO_2 effect as compared to more sophisticated radiation models which treat the stratosphere explicitly.

The author concluded that natural variability is certainly an important cause of climatic fluctuations nd may explain the difference between the observations and model results from purely external forcing.

1. **RODIN, L.E.**

2. 1979

3. Primary productivity studies in biosphere reserves (methods and initial results).

4. IN: J.F. Franklin and S.L. Krugman, Coordinators, Selection, management and utilization of biosphere reserves, Proceedings of the United States - Union of Soviet Socialist Republics Symposium on Biosphere Reserves. U.S. Department of Agriculture, Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-82. p. 198-215

5. a. U.S.S.R.

   b. Larch, Scots pine

   c. Biomass (tree, shrub/herb, moss/lichen)

6. The author's review of primary production studies within biosphere reserves of the U.S.S.R. includes information on one site from the central taiga region. Vast amounts of tree biomass data have been accumulated in studies since 1955 at the Institute of Forest and Timber, Siberian Branch of the U.S.S.R. Academy of Sciences, 28 km north of Yakutsk.

The following table summarizes the standing crop for three ages of pine stands in the central taiga.

	Pine standing crop, t/ha, dry wt.		
	100 yr	140 yr	180 yr
Trunk and crown	62.3	90.9	99.3
Needles and leaves	3.1	3.4	4.0
Underbrush	1.8	3.9	1.3
Ground cover	4.3	3.2	3.8
Total above ground	71.5	101.4	108.4
Roots	13.7	23.7	25.4
Total phytomass	85.2	125.1	133.8

Larch forests prevail on vast expanses of Yakutia. Productivity of these forests is noticeably higher than that of pine forests in the same zone of the central taiga as indicated in the table below:

	Larch standing crop, t/ha, dry weight				
	50 yr	90 yr	130 yr	170 yr	200 yr
Trunk and crown	53.4	140.0	107.2	117.5	118.4
Needles and leaves	2.2	3.4	2.1	2.0	2.1
Underbrush	0.0	0.1	0.3	0.3	1.3
Ground cover	0.1	0.3	1.1	1.5	2.6
Total above ground	55.7	143.7	110.6	121.3	124.4

1. RODIN, L.E. and N.I. BAZILEVICH

2. 1964

3. The biological productivity of the main vegetation types in the northern hemisphere of the old world.

4. Translated from Doklady Akademii Nauk SSSR 157:215-218, by Mrs. R.R. Inston, Commonwealth Forestry Bureau

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb, moss/lichen)

6. It is in forest communities that the greatest accumulation of organic matter is observed. In moist tropical forests the accumulation can be 500,000 kg/ha or more; this value, however, does not greatly exceed the corresponding values for subtropical forests and broadleaved forests of the temperate zone (410,000 to 370,000 kg/ha). The biomass in northern taiga spruce forests averages about 100,000 kg/ha. In tropical forests, the assimilating ('green') parts, which include the leaves not only of trees and shrubs but also of plants in the ground cover, account for up to 8% of the biomass (40,000 kg/ha); in subtropical forests the figure is 12,000 kg/ha, or 3%, and in broadleaved forests of the temperate zone, 4,000 to 5,000 kg/ha, or about 1%. In coniferous forests of the temperate zone the green parts increase to 8,000 to 16,500 kg/ha, or 5 to 8%. On the other hand, the perennial aerial parts account for a fairly stable proportion (70 to 77% of the biomass), with sharp fluctuations in absolute values. The absolute weights of underground organs are very similar in broad-leaved forests of all zones (82,000 to 96,000 kg/ha); the relative contribution of the underground organs to total forest biomass varies comparatively little in all the zones (18 to 26%).

Increment, the annually increasing mass of leaves and herbaceous organs plus the increment of wood and roots, is highest in moist tropical and subtropical forests (32,500 and 24,500 kg/ha/yr), and far exceeds that of broad-leaved and coniferous forests of the temperate zone (13,000 to 4,500 kg/ha/yr). The values for increment and litter in forests govern the quantity of organic matter that is retained in the community (the net increment). There is a general tendency for the net increment to increase from the northernmost forests towards equatorial forest communities.

The relative figures for litter as a percentage of the total biomass indicate the role of the various plant communities as accumulators of matter and energy. Forests of the temperate zone occupy first place in this respect, retaining the greatest part of the organic matter that is formed through the use of solar energy; the litter in these makes up only

Continued ...

1.5% of the biomass in oak forests, 1.6 to 2% in southern and central taiga spruce forests, 3% in beech forests, and 4% in northern taiga spruce forests. Biomass and increments (kg/ha x 100) are summarized for four boreal ecosystems in the table below.

	1**	2	3	4
Biomass*				
Green parts	1,000	2,600	3,300	370
Perennial aerial parts	80	160	165	151
Roots	700	1,850	2,400	179
Increment	220	600	735	40
Litter	45	70	85	34
Green parts in the litter	35	50	55	25
Leaf litter (for forests)	18	30	34	23
Net increment	15	25	30	-
Litter and surface humus, or dead 'mat' in steppe	10	20	30	9
Ratio of litter-and-humus to green parts in the litter	300	450	350	more than 1,000
	17	15	10	more than 100

* all units of biomass, litter and humus in this table are kg/ha x 100 and all units of increment are kg/ha/yr x 100

** 1 Northern taiga spruce forests
2 Central taiga spruce forests
3 Southern taiga spruce forests
4 Forest Sphagnum bogs (from unpublished work by the authors)

The largest quantity of litter and surface humus is found in shrubby tundras (83,500 kg/ha), followed by central, southern and northern taiga spruce forests (45,000, 35,000 and 30,000 kg/ha, respectively) and then by broad-leaved forests (15,000 kg/ha). The accumulation of litter and surface humus indicates low decomposition of organic matter and a decrease in the rate of energy release. The ratio of the quantity of litter plus surface humus to the litter from green parts, as shown in the bottom row of the table above, varies greatly in various ecosystems. Except for Sphagnum bogs, where it exceeds 100, its value is highest (92) for shrubby tundras, followed by northern taiga spruce forests (17), decreasing southwards through the subzones of the taiga; in broad-leaved forest this ratio is 3 to 4, in steppes 1.5 to 1, in subtropical forests 0.7, and in moist tropical forests only 0.1.

1. RODIN, L.E. and N.I. BAZILEVICH

2. 1967

3. Production and mineral cycling in terrestrial vegetation.

4. English translation of original text, Dinamika organicheskogo veshchestva i biologicheskiy krugovorot zol'niykh elementov i azota v osnovnyky tipakh rastitel'uosti zemnogo shchara, (1965), edited by G.E. Fogg. Oliver and Boyd, London. 288 p

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb, moss/lichen)

6. This comprehensive text devotes separate chapters to each of the several distinct zones: tundra and forest-tundra; coniferous and mixed forests; deciduous and broad-leaved forests; steppeland; deserts; and tropical, subtropical and savana types. For each zone there are detailed data on chemical composition of plants, accumulation of chemical elements in plant biomass and their uptake in net primary production and release with litter fall, accumulation and decomposition of plant remains, and features of soil biological processes.

The author's tables of biomass and net primary production for forest ecosystems of the boreal zone are too detailed to summarize here. Some of the main features of primary production in boreal forests are summarized below.

Although the absolute net primary production of open spruce woods in the forest-tundra is similar to that of spruce woods in the taiga zone, the green portion is not more than 40% of the latter, whereas it is up to 72% in the spruce woods of the forest-tundra because of the particularly large contributions made by the ground flora in the forest-tundra communities. As in the tundra, the dynamics of organic matter and, therefore, the biological cycle of mineral elements in forest-tundra areas are largely determined by the annual growth and mortality of ground vegetation. The true increment for forest communities in the forest-tundra is very small, being only approximately 300 kg/ha. Most of this increase is accounted for by green mosses and the perennial above-ground organs of trees. The amount of true growth in forest-tundra forests is considerably less than the amount in coniferous swamp forests, and only 1/10 to 1/20 of the amount in spruce forests in the taiga zone. These facts indicate the extremely adverse climatic conditions along the northern limit of forest growth.

The total amount of organic matter varies from 50 to 350 t/ha in northern coniferous forests. The contribution of mosses to the plant biomass is particularly increased in waterlogged forests and may reach 5 to 10 t/ha. Underground biomass may also be significant, as feeding roots have been

Continued ...

noted to have standing crops of up to 580 kg/ha, dry weight, in the upper 120 cm of soil in spruce woods of the central U.S.S.R. taiga. When the forests are waterlogged the quantity of feeding roots is reduced.

Green assimilating organs account for between 3 and 9% of the total plant biomass in developed fully mature communities, and for a higher proportion in young communities. The proportion is also higher in waterlogged and low-quality open forests because of the well-developed ground flora. Green parts comprise 40% of the total biomass in wooded swamps and more than 90% in treeless moss bogs. Characteristically, the absolute mass of green organs is not dependent on the total amount of organic matter and varies within a comparatively narrow range of 5 to 20 t/ha. It is the radiation balance, especially the intensity of light and its utilization by plants, that is responsible for the comparative stability of the proportionate contribution of green parts, and also of needles or tree leaves in communities of different ages. Conversely, the absolute amount of matter in the perennial above-ground organs of communities is directly dependent on the total plant biomass. It is evident that the relative proportion of perennial forms of biomass is lower in the early stages of formation of a community, whereas that of the green parts and roots is considerably higher. It is not until the plant biomass reaches 80 to 100 t/ha that a balance is established between the structural elements; this occurs about the 25th year.

1. RODIN, L.E. and N.I. BASILEVICH

2. 1968

3. World distribution of plant biomass.

4. IN: F.E. Eckardt, Editor, Functioning of terrestrial ecosystems at the primary production level. Proceedings of the Copenhagen Symposium, UNESCO, Belgium. p. 45-52.

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree)

6. The authors' estimates of productivity in three subdivisions of the boreal forest (taiga) are summarized below:

Biomass and productivity parameters	North taiga	Middle taiga	South taiga
Biomass, above-ground and below-ground (t/ha)	100	260	330
Green parts (t/ha)	8	16	16.5
Green parts (%)	8	6	6
Perennial overground parts (t/ha)	70	185	240
Perennial overground parts (%)	70	71	73
Roots (t/ha)	22	60	73.5
Roots (%)	22	23	22
Net primary production (t/ha/yr)	4.5	7	8.5
Litter-fall (t/ha/yr)	3.5	5	5.5
Green parts in litter-fall (t/ha/yr)	1.8	3	3.4
Leaf-fall in forests (t/ha/yr)	1.5	2.5	3
Real primary production (t/ha/yr)	1	2	3
Litter (t/ha)	30	45	35
Ratio: litter/litter-fall of green parts	17	15	10

At the time that this article was prepared, the authors indicated that the next step of their research would be the establishment of correlations between the amount of plant biomass, net primary production and environmental factors such as latitude, solar radiation, amount and régime of rainfall and temperature régime.

1. RODIN L.E., N.I. BAZILEVICH, and N.N. ROZOV

2. 1975

3. Productivity of the world's main ecosystems.

4. IN: Productivity of world ecosystems, Proceedings of a Symposium presented at the V General Assembly of the Special Committee for the International Biological Program. National Academy of Sciences, Washington, D.C. p 13-26

5. a. Northern hemisphere

   b. Nil

   c. Biomass (tree, shrub/herb, moss/lichen)

6. The authors calculated the total phytomass of 106 terrestrial soil-plant formations, grouped into bioclimatic areas and thermal belts, along with estimates of annual productivity. The total phytomass of the land is estimated to be 2.4×10^{12} metric tons (t) dry weight. The bulk of this organic mass is in the tropical zone (56%), followed by the boreal (18%), subtropical (14%), subboreal (12%) and polar (1%) zones. The majority of phytomass is concentrated in forests (82%). Total phytomass in the world's oceans amounts to 1.7×10^{8} t, which is about 15,000 times smaller than that of the land.

The total primary production of the land is estimated to be 1.72×10^{11} t/yr. The tropical belt produces 60% of this total; subtropical, 20%; subboreal, 10%; boreal, 9%; and polar, 0.8%. Forests produce 49% of primary production of the land. The total primary production of the oceans is estimated at 4.7 to 7.2×10^{10} t/yr. Hence, the oceans contribute approximately one-third as much primary production as do terrestrial plant communities. The total primary production of the earth is calculated as being 2.35×10^{11} t/yr of dry organic matter. The earth's living organic matter (biomass) is dominated (99%) by photosynthesizing organisms.

The 106 soil-vegetation formations recognized by the authors included 17 hydrothermal (bioclimatic) subzones within the boreal thermal zone with phytomass and production estimates as listed on the next page.

Continued ...

	Phytomass t/ha	Phytomass 10^6 t	Production t/ha/yr
Maritime herbaceous-forest formations on volcanic ash	100	1,350	10.0
Open forest-tundra woodland and northern taiga forest on gley-podzolic soils	125	11,000	5.0
Same, on gley-permafrost taiga soils	100	12,190	4.0
Middle taiga forest on podzolic soils	260	92,846	7.0
Same, on permafrost taiga soils	200	49,260	6.0
Southern taiga and mixed broadleaf and needle forest on turf-podzolic soils	300	95,460	7.5
Same, on yellowish-podzolic soils	350	13,755	10.0
Same, on turf-calcareous and turf-gley soils	350	10,535	10.0
Same, on taiga bog soils with bogs	80	6,824	4.0
Small-leaf forest on gray and gray solodized forest soils	200	4,540	8.0
Broadleaf forest on gray forest soils	370	26,307	8.0
Bogs	35	3,892	3.5
Floodplain formations	60	3,558	6.0
Mountain-taiga forests on mountain podzolic soils	170	45,832	6.0
Same, on mountain permafrost soils	160	48,640	5.0
Mountain meadows on gray mountain forest soils	300	7,560	7.5
Mountain meadows on mountain meadow soils	35	5,512	12.0
TOTAL	189	439,061	6.5

The relative importance of the boreal zone, in comparison with other zones, and with total terrestrial, total ocean and total earth phytomass and mean annual production is summarized below.

Thermal belts	Area 10^6 km^2	Mean Phytomass (t/ha)	Total Phytomass (10^9 t)	Mean Annual Production (t/ha/yr)
Boreal humid and semi-humid	23.20	189.2	439.06	6.5
Total sub-boreal	22.53	123.6	278.67	7.9
Total sub-tropical	24.26	133.5	323.90	14.2
Total tropical	55.35	243.3	1,347.10	18.5
Total terrestrial	133.40	180.1	2,402.50	12.8
Total ocean	361.00	0.005	0.17	1.7
Total earth	510.30	47.1	2,402.71	4.5

Phytomass production per unit area of land in humid regions increases from less than 2 t/ha/yr on the average in the polar zone to between 6 and 13 t/ha/yr in the boreal and subboreal zones and between 26 and

Continued ...

29 t/ha/yr in subtropical and tropical zones. These geographic regularities of distribution of annual increment (and also phytomass reserves) correlate well with climatic factors, particularly the influx of heat (R, in kcal/cm^2/yr) and the degree of moistening (determined by the dryness factor, R/Lr, where r is precipitation rate and L is the latent heat of phase conversion). An increase in heat reserves results in an especially large increase in production when R is less than 40 kcal/cm^2/yr (regions north of the middle-taiga subzone). When R is more than 40 kcal/cm^2/yr, moisture is the key limiting factor. The annual increment of zonal soil vegetation formations is the highest in regions with less than 40 kcal/cm^2/yr and R/Lr greater than 1 (1.2 for northern taiga and 1.5 for tundra) and not in regions with R greater than 40 kcal/cm^2/yr and R/Lr less than 1 (0.7 for subtropics and 0.5 for tropics). Because of these correlations, the authors state that conclusions drawn by previous researchers with respect to climatic control over biotic production have not been entirely accurate.

Thus, the authors conclude that if heat reserves are sufficient, excess precipitation will result in higher production; even if moisture is ample, if heat reserves are insufficient, lower production will result. Yet, a simple temperature:moisture ratio fails to account for all possible patterns of distribution of primary productivity. It is also important to consider the duration of the growing season and effective precipitation (precipitation minus surface discharge). A.M. Ryahchikov (1968) has proposed a hydrothermal productivity potential (Kp) calculated as

$$Kp = \frac{WT_v}{36R}$$

where W is the average annual effective precipitation (mm), T_v is the duration of the growing season in terms of 10-day periods (36 10-day periods in a year); and R is average annual radiation balance in kcal/cm^2. The hydrothermal productivity potential correlates extremely well with biomass production.

Generalizations of potential primary productivity may best be estimated by evaluating the ratio between annual increment and phytomass of the continents. Many publications give ratios of increment to phytomass from 0.15 to 1.9% with the exception of Deevey, Leith, Whittaker, and the authors of this paper. Yet, actual sampling of different types of terrestrial vegetation shows that there are few plant communities which yield such low ratios. Thus, the ratio between annual increment and phytomass reserves for tundra is between 10 and 20%, for boreal and subboreal forests 2 to 5%, for subtropical forests 5 to 6%, for tropical forest 8 to 10%, for the grass communities of steppes, prairies and savannas 20 to 55%, for desert communities 30 to 75%, and for communities of annual field crops it is 100%. Thus, the absolute value of 1.09 to 1.72 x 10^{11} t and the relative (6 to 7%) values for annual increase in phytomass on land seem to be consistent with those of Whittaker.

1. ROSENZWIEG, Michael L.

2. 1968

3. Net primary productivity of terrestrial communities: prediction from climatological data.

4. American Naturalist 102:67-74

5. a. Northern hemisphere

   b. Mil

   c. Climate (precipitation, temperature), Climate/growth (direct relationships)

6. Previous research has shown that the actual evapotranspiration (AE) in a terrestrial environment is qualitatively related to the amount of vascular plant activity. AE may be defined as precipitation, minus runoff, minus percolation. AE may be thought of as the reverse of rain. It is the amount of water actually entering the atmosphere from the soil and the vegetation during any period of time, that is, the evaporation plus the transpiration. Obviously, this atmospheric entry simultaneously requires water and sufficient energy to make the phase transfer of the water possible. Thus, AE is a measure of the simultaneous availability of water and solar energy in an environment during any given period of time.

Biotemperature and potential transpiration (PE) are linearly related. PE may be defined as the amount of evapotranspiration that could occur if the soil of a large area having vegetation typical of the surroundings were kept constantly wet, that is, at or above field capacity. In fact, PE is the solar energy estimate used in calculating AE. Hence, it is reasonable to hypothesize that AE is an environmental variable usable for the purpose of predicting production.

To test the hypothesis both productivity and AE should be measured simultaneously at the same study site. Although some meteorological data have been collected during productivity work, such data are only rarely convertible into estimates of AE. The author used methods developed by Thornthwaite to estimate AE from a knowledge of the latitude of a place and its mean temperature, month by month, and its precipitation, month by month.

The author assumed that a 1,000 m increase in altitude was accompanied by a 4.1° C decrease in biotemperature, and by a 241.6 mm decrease in AE. Meteorological data confirmed this slope and determined the intercept. The resulting productivity prediction equation, including 5% confidence intervals for the slope and intercept, was

$$\log_{10} \text{NAAP} = (1.66 \pm 0.27) \log_{10} \text{AE} - (1.66 \pm 0.07),$$

Continued ...

where AE is the annual actual evapotranspiration (mm), and NAAP is the net annual above-ground productivity ($g/m^2/yr$).

Although the author stressed the hypothetical nature of the correlation between AE and productivity, actual evapotranspiration was shown to be a highly significant predictor of the net annual above-ground productivity in mature terrestrial plant communities. Communities included ranged from deserts and tundra to tropical forests. It is hypothesized that the relationship of AE to productivity is due to the fact that AE measures the simultaneous availability of water and solar energy, the most important rate-limiting resources in photosynthesis.

1. ROWE, J.S.

2. 1972

3. Forest regions of Canada.

4. Department of Fisheries and the Environment, Canadian Forestry Service, Ottawa. Publication No. 1300. 172 p

5. a. Canada; Index maps (all in boreal region); All boreal forest sections in Canada

   b. Aspen, balsam poplar, white birch, balsam fir, jack pine, larch, black spruce, white spruce

   c. Climate/growth (direct relationships, latitude), Climatic variation (regional, temperature, precipitation)

6. The boreal forest region comprises the greater part of the forested area of Canada, forming a continuous belt from Newfoundland and the Labrador coast westward to the Rocky Mountains and northwestward to Alaska. White and the black spruces are characteristic species; other conifers are tamarack which is absent only in the far northwest, balsam fir and jack pine prominent in the eastern and central portions, and alpine fir and lodgepole pine in the extreme western and northwestern parts. Although the forests are primarily coniferous, there is a general admixture of broadleaved trees such as white birch and its varieties, trembling aspen and balsam poplar; the latter two species play an important part in the central and south-central portions, particularly in the zone of transition to the prairie. The proportion of black spruce and tamarack rises northward, and with increasingly rigorous climatic and soil conditions the closed forest gives way to the subarctic open lichen-woodland which finally merges into tundra. In the east there is a considerable intermixture of species from the Great Lakes-St. Lawrence forest.

A notable feature of the climatic maps is that temperature parameters (permafrost zones and mean annual length of the growing season) have isolines that trend northwest-southeast, more or less parallel with the northern and southern boundaries of the boreal forest region. In contrast, moisture regions in Canada are defined by generally north-south isolines that bear little similarity to the boundaries of the boreal forest region. The author's map of moisture indices were based on the relation between water deficiency, surplus and need (potential evapotranspiration). The ratio of water deficit to need gives an index of aridity; the ratio of water surplus to need a humidity index. Positive indices denote moist climates; negative indices denote dry climates. Within Canada's boreal forest region, moist climates (with a positive moisture index) occur eastwards from a line that runs southeastwards from the vicinity of Coppermine to the southeastern corner of Manitoba, and also in the western parts of the boreal forest region in Yukon and northern British Columbia; dry climates dominate the boreal forest region from the Coppermine-southeastern Manitoba line westward to the Rocky Mountains and Mackenzie Mountains.

1. ROWE, J.S. and G.W. SCOTTER

2. 1973

3. Fire in the boreal forest.

4. Quaternary Research 3:444-464

5. a. Canada, Alaska; Index maps (all in boreal region); All boreal forest sections in Canada

   b. Black spruce, white spruce

   c. Climate/growth (indirect influences)

6. The boreal forest in North America owes much of its floristic and faunistic diversity to periodic fires ignited by lightning and more recently by man. Fire is known to exert a significant effect on vegetational composition, on soil chemical properties and thermal regime. In turn, fire is itself influenced by the nature of geographic landscape ecosystems according to their surface forms, accumulations of organic materials, and susceptibility to drought. The authors stressed that fire should be viewed as a normal ecological process in the boreal forest.

Although the average yearly solar radiation over the boreal forest is fairly high, 250 to 300 langleys per day, the continental climate plus the marked seasonality of solar energy results in lower mean annual temperature and longer winters. Because of the differential heating of earth and air, mean soil temperatures are 2 to 5° C higher than mean air temperatures so that between the -1° C and -6° C air temperature isotherms there is a broad zone wherein discontinuous permafrost is strongly influenced by vegetation cover, soil and topography. North of the -6° C mean temperature isotherm, permafrost is continuous under the subarctic lichen woodland. Water is a heat sink and tall trees and shrubs along valleys and the margins of large northern lakes commonly show the effects of ameliorated climate and warmer than normal soils.

Changes in the composition and structure of vegetation parallel the diminishing energy gradient from south to north. For example, a cross section of the boreal forest in central western Canada illustrates, from prairie to tundra edge, the decline in prominence of broad-leaf trees such as aspen, the steady increase in conifers, and a decrease in tree heights and canopy densities. Lessened activity of insects and diseases in an increasingly rigorous environment may explain why tree ages reach their greatest values within the boreal zone at the northern edges of the zone.

Age structure of forest stands gives evidence of periodic disturbance. The majority of boreal forest stands are less than 100 yr old; spruce stands older than 250 yr are rarely found except in areas protected from fire. Observations in the northern clay belt of Ontario noted that dry conditions, accompanied by high fire frequency, occur at about 30 yr intervals.

Continued ...

Rowe, J.S. and G.W. Scotter. 1973. Continued

Statistics suggest that the average annual burn in Canada is 0.3% of the whole forest area, which can be interpreted as meaning that every forest will probably burn once every 300 yr. However, it is likely more accurate to predict that certain susceptible areas will burn many times while others will escape unscathed for long periods.

In the interior of Alaska white spruce stands that have been fire-free for 200 yr are surrounded by areas that burned every 40 to 60 yr. The old spruce are not remnants of a once more extensive forest but are simply relatively fire-proof "islands" characterized by a more moist physiography and surrounded by less stable and drier younger stands renewed by fire.

There is no reason to believe that age brings increasing fire susceptibility. The oldest forests in the northwest boreal region, some in excess of 300 yr, are white spruce stands. They often occur as pure stands on the moist floodplains of rivers, and various explanations for their presence are proposed. There is good evidence that fires sometimes destroy such alluvial white spruce stands, although fire frequency is much less than on the adjacent drier and more exposed uplands where young stands of pine, black spruce and aspen dominate.

There are various other effects of fire, direct and indirect, on the growth rates of vegetation and on the productivity of sites. In the cataclysmic type of fire described by Kiil and Grigel (1969), soils can be thoroughly "ploughed" as convective winds uproot trees over large areas. By this means, down-leached nutrients are returned to the surface. On the other hand, erosion may result, especially in hilly terrain or where the soils are sandy. For example, there is evidence in the great sand areas on the south shore of Lake Athabasca in northwest Saskatchewan that forest fires have initiated cycles of dune-forming activity. Allusion has been made to the accumulation of humus in northern climates due to slow breakdown rates. Fire is believed by some to be the necessary agent of mineralization, restoring plant nutrients for recycling. Whether the "nutrient lock-up" hypothesis is true or not, there can be no doubt that accumulated organic matter is usually a less favourable substratum for forests than is mineral soil.

The authors concluded that there is plenty of evidence that productivity can be higher in early than in late stages of ecosystem development, so that rejuvenation by periodic perturbations may often prove desirable. Furthermore, a mosaic of landscape ecosystem types, from "young" to "old", is desirable aesthetically as well as for long-range land-use purposes. Fire has been the usual initiator of perturbations, keeping boreal forest ecosystems productive.

1. SAKAI Akira, Shizuo YOSHIDA, Mitsuru SAITO and S.C. ZOLTAI

2. 1979

3. Growth rate of spruces related to the thickness of permafrost active layer near Inuvik, northwestern Canada.

4. Low Temperature Science, Series B 37:19-32

5. a. Canada; Index map NR-7/8/9; District of Mackenzie; B.23b, B.32

   b. Black spruce, white spruce

   c. Climate (temperature), Climate/growth (direct influences), Treeline studies (growth, climate)

6. Growth rates of white spruce and black spruce from different topographical sites near Inuvik were studied with special reference to thickness of active layer (the annual layer of thaw). An important effect of permafrost in interior Alaska and northwestern Canada is that of holding water near the ground surface. The annual precipitation in this region is below 250 mm, and topographic variables such as aspect and slope are of special importance to the distribution of vegetation and soils. The best sites for tree growth are on south-facing slopes and river alluvium where soils are well-drained and have a thick active layer. The growth rate of white spruce at different topographic sites was related to the thickness of the active layer. In many white spruce, height growth reached a maximum at the age of 20 to 40 yr, and then abruptly decreased, remaining at low levels. However, in black spruce such conspicuous change was not observed in the growth rate which remained at low levels for about 100 yr and then increased gradually.

A conspicuous difference in the pattern of growth rate was evident between white and black spruces. A slow but steady growth appears to be characteristic for black spruce, unlike white spruce which has a fast growth rate at younger ages. Growth rate of white spruce in a clump in the treeless tundra was the lowest among the white spruce sampled near Inuvik. The stem volume at 64 yr was only 1/25th that of white spruce growing in a more favourable location farther south. The low values for growth rate probably represent near-minimum values for conifers, and are clearly related to the severe climate in treeless tundra during the growing season.

The low growth rates of white spruce trees that grow on north-facing slopes, bogs and muskegs may be related to the effect of topography (reduced incoming radiation, or poor drainage) that favours the development of an insulating organic mat. The result is cool soil temperatures, making the bioclimate similar to that of forest patches in the tundra. The thickness of active layer is a reliable indicator of conditions that influence the distribution and growth of trees. The greater productivity of spruces on south-facing slopes where there are

Continued ...

Sakai A., S. Yoshida, M. Saito and S.C. Zoltai. 1979. Continued

deep active layers may be explained by a combination of factors such as good drainage, high soil temperature, availability of nutrients, and well developed soil.

The authors conclude that the presence of extensive wet areas in a region with low precipitation is largely the result of the underlying permafrost. Increases in the thickness of active layer, caused by better surface drainage on steeper slopes, more permeable materials, the nearness of a stream, or by warmer soil temperatures on south-facing slopes create soils with improved internal drainage. On such sites, white spruce is established and grows at a much faster rate than white or black spruce on waterlogged soil with a thin active layer.

1. SANDERSON, Marie

2. 1948

3. Drought in the Canadian northwest.

4. Geographical Review 38:289-299

5. a. Canada; Index maps (all in Alberta, District of Mackenzie, Manitoba, Saskatchewan); All boreal forest sections in Alberta, District of Mackenzie, Manitoba and Saskatchewan

   b. Nil

   c. Climate (precipitation, temperature), Climatic variation (regional, temperature, precipitation)

6. In this paper the author gives evidence that the prairie provinces and Northwest Territories have a dry subhumid climate according to the Thornthwaite classification. At the time of the study, there were few climatic stations and the conclusions were tentative. The only part of the study area that was classified as a humid climate was the Hudson Bay coastal area near Churchill, Manitoba. Northern and eastern Manitoba were mapped with a moist subhumid climate and the remainder of the forested portions of the study region had a dry subhumid climate.

Agricultural research at experimental stations in the Northwest Territories along the Mackenzie River Valley considered lack of moisture one of the major limits to crop production. Other hazards to crop production were late spring and early fall frosts and short summer growing seasons.

A series of experiments were cited by the author where improvements to moisture conditions resulted in growth and yield improvements of agricultural crops. An exploratory soil survey along waterways in northern Alberta indicated that the mean average summer temperatures were usually high enough for good crop growth, and although there was some danger of late spring and early fall frosts, drought was a much more serious handicap to crop production. In areas of Manitoba north of Lake Winnipeg, in contrast to conditions in Saskatchewan, Alberta and the Northwest Territories, temperature seemed to be the limiting factor for crop production.

1. SARVAS, R.

2. 1970

3. Temperature sum as a restricting factor in the development of forest in the subarctic.

4. IN: Ecology of the subarctic regions, Proceedings of the Helsinki symposium, UNESCO, Paris. p. 79-82

5. a. Finland

   b. Norway spruce, Scots pine

   c. Climate/growth (direct relationships, latitude), Growing season (degree-day totals)

6. There are several climatic factors that determine the northern tree limit, but temperature is undoubtedly the most important. The effects of temperature are manifold and scarcely describable with any one regression. However, it has been shown that many annual events of plant growth can be measured by temperature sums. The following equation for temperature sums has proved useful.

$$T_{+5^\circ C} = \sum_{n=1}^{n} (t_n - 5)$$

where $T_{+5^\circ C}$ = the temperature sum based on a threshold value of 5° C, "n" = the total number of days with a mean temperature higher than +5° C and t_n = the mean temperature of those days.

In Finland, detailed studies have been undertaken to determine the minimum length of time to which trees can adapt their growing period. A recorded gradient of changes from southern to northern Finland was as follows. The average temperature sum of Scots pine anthesis at Tuusula was 230 degree-days, which is 7.2% of the average annual temperature sum of 1,333 degree-days. At Rovaniemi, 201.3 degree-days was the average annual temperature sum for anthesis of Scots pine, which is 22.2% of the average annual temperature sum of 904 degree-days. In Kittila, the required temperature sum for anthesis was 195 degree-days, which is 28.4% of the 686 degree-day average annual temperature sum. In Utsjoki 196 degree-days were required, or 32.4% of the average annual temperature sum of 605 degree-days. This indicates that further north the annual period of growth for Scots pine is increasingly poorly adapted to the local average annual temperature sum.

The author concluded that 950 degree-days seems to be about the smallest average annual temperature sum to which the annual period of Scots pine population in northern Europe has become genetically adapted. The

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general presumption previous to this study had been that the line is much further north, closer to the northern treeline. In Finland, around 40% of the forested area falls north of this 950 degree-day isoline. North of this line, the annual growth period of Scots pine stops prematurely in most years. One of the best known consequences is that seed matures only in warmer than average summers. The existence of Scots pine north of this limit is largely dependent upon warmer than average growing seasons.

The author noted that the existence of forest does not necessarily require that trees have in every respect accommodated themselves to the climate where they grow. The forests of northern Scandinavia are an example in which the tree population has not adapted itself fully to the length of the growing season.

1. SCHMITT, W.R., C.K. STIDD and J.D. ISAACS

2. 1975

3. Ice ages and northern forests.

4. IN: G. Weller and S.A. Bowling, Editors, Climate of the Arctic, Twenty-fourth Alaska Science Conference. p. 117-119

5. a. Northern hemisphere

   b. Mil

   c. Climatic change (hypotheses)

6. Some investigators see the world's climate as being in precarious balance between powerful cooling and warming trends. One mechanism by which climate may be modified is the albedo change occasioned by changes in vegetation cover. This paper examines the climatic effectiveness of forest removal.

Inter-annual changes in cover of snow and pack-ice alter the earth's energy budget more powerfully than could any expected extraterrestrial mechanism by virtue of the following feedback: as ice and snow advance, the earth's albedo increases, with a resulting decrease in solar heat absorption and an ever more favourable condition for continued ice and snow advance. This feedback cycle could perhaps be set in motion by a transient albedo increase, as for example by the removal of northern evergreen forests which would lead to a sharp reflectivity increase in winter and a moderate one in summer. Forest removal could either be advertent, as in the clearing for cultivation or logging, or it could be inadvertent, as in natural and accidental forest fires.

Budyko (1969) estimated that a 1.6% reduction in solar radiation would be enough to trigger an ice advance to a mean latitude of 50° N. This estimate was independently confirmed by other researchers using a climatic model based on energy balance and exchange. The authors suggested that the globe's climate is not that unstable, and that a steeper temperature gradient equator-to-pole would accelerate the general circulation of the atmosphere and oceans with consequent greater mixing and greater heat transfer. Although the effects of the oceans may exacerbate the formation of glaciers through increased high-latitude cloud cover and precipitation, they would probably also limit the glaciers' low-latitude advance.

The authors suggest that artificial warming might soon override any cooling that could be generated by forest removal. Manipulating the globe's albedo by control of forests could be one of the tools of climatic modification in the future.

1. SCHOVE, D. Justin

2. 1950

3. Tree rings and summer temperatures, A.D. 1501-1930.

4. Scottish Geographical Magazine 66(1):37-42

5. a. Finland, Norway, Sweden

   b. Scots pine

   c. Climate change (dendrochronology), Climatic variation (temporal, temperature)

6. Dendrochronology or dating by tree-ring patterns involves three initial limitations: a) only one species should be considered at one time; b) the trees should be from one climatically uniform area; c) the measurements of growth for each year should be corrected for age by a single objective method. The first restriction is necessary because each species has its own peculiar ecology; each type, for instance, has its own characteristic reactions to insect pests. The second principle is necessary because rainfall and snowfall regimes vary considerably from place to place. The final restriction is necessary because trees grow more quickly when they are young; for a series of growth-values to be useful meteorologically, they should be based on trees of different ages and corrected according to the average growth of the trees in question.

The temperature anomaly of a particular growing season is usually similar over a wide area extending at least from northern Scotland to Finland. It can be correlated with the pressure difference between Finland and East Iceland, or more generally with the extent and strength of the summer monsoon. The northerly winds of this little-known "summer monsoon" normally affect West Russia, but they spread to Scandinavia particularly in June; occasionally they extend as far as the British Isles to give a week of cloudy weather usually attributed to a "Buchan cold period". The author used the calculated temperature series for Trondheim which extends back to 1761 and from this the mean temperatures for May to August were extrapolated.

The author developed the following formula connecting tree-growth and temperature in any particular summer:

$$t \pm 6 = 9.5d - 82.5$$

where t = temperature anomaly from May to August at Trondheim (°C x 10)
d = mean tree-growth in the five areas (mm x 10)

Tree-growth in individual years varied from over 1.5 mm in the warm summer 1828 to less than 0.6 mm in the cold summer 1821. The ten summers in which tree-growth was greater than 1.15 mm were warm and, except for

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1829 and 1861, were actually not less than 2° C above the 1901-30 normal. The nine summers in which tree-growth was less than 0.7 mm were invariably cold.

The relationship between tree-growth and temperature applies not only to individual years but also to groups of years. The formula for five-year periods is very similar, but the probable error is halved and is only 0.3° C in comparison with an interquartile range of 1.0° C. The formula is:

$$t \pm 3 = 9.75d - 85$$

The following clusters of cold and warm summers can be inferred from the tree-ring curve:

1547 - 1554	Cold	1635 - 1645	Cold
1563 - 1581	Warm	1657 - 1668	Warm
1587 - 1601	Cold	1684 - 1694	Warm
1604 - 1610	Warm	1710 - 1720	Cold
1614 - 1620	Cold	1733 - 1744	Cold

The periods of rapid and slow tree-growth in northern Scandinavia, as indicated by 30-year means can be summarized as follows:

Period	Tree growth		Inferred temperature anomaly
up to 1581	Moderate	0.9 mm	0° C
1582 - 1653	Slow	0.8 mm	-1.0° C
1655 - 1678	Moderate	1.0 mm	+1.0° C
1684 - 1703	Rapid	1.1 mm	+1.5° C
1708 - 1751	Very slow	0.8 mm	-1.0° C
1751 - 1834	Fairly high	0.95 mm	+0.5° C
1835 - 1928	Moderate	0.9 mm	0° C
1928 - 1950	Rapid	?	+

1. SCHOVE, D. Justin

2. 1954

3. Summer temperatures and tree-rings in North-Scandinavia, A.D. 1461-1950.

4. Geografiska Annaler 36:40-64

5. a. Finland, Norway, Sweden

   b. Nil

   c. Climate/growth (direct relationships), Climatic change (dendrochronology, proxy data)

6. Summer temperatures in Scandinavia can be determined since the eighteenth century from thermometric records, notably those of Uppsala (since 1739), Stockholm (since 1756) and Trondheim (since 1761). Comparison of tree-ring and thermometric indices since 1761 showed that the mean ring-width varied linearly with May-August temperatures. The tree-ring evidence itself can only indicate a probable temperature; its advantage is that it can be used to determine the nature of the summers for several centuries before the instrumental observations began. The summer temperature, moreover, is a clue to atmospheric pressure and to changes in circulation, and it can be shown that the narrowness of the ring is closely related to the strength of the northerly "monsoon" in North Scandinavia.

In general, in dry areas the width of tree-rings reflect rainfall and in cold areas the tree-rings reflect temperature. In intermediate regions, such as Germany, tree-rings are ambiguous as climatic indicators, but near the northern treeline the width of the ring is known to be closely dependent upon the temperature of a short growing season, as shown by investigators both in Alaska and in Scandinavia.

The author noted that for western Alaska, Giddings (1943) had identified three distinct types of responses of tree growth to July temperatures: 1) the "timberline" type where mean July temperature is less than 13° C and in which growth depends very closely upon temperatures during the short growing season in June and July; 2) the "summer-marginal forest" type where mean July temperature ranges between 13° C and 15.5° C and in which growth still depends mainly on temperature of the growing season but with the latter now longer to include both May and August; and 3) the "coniferous forest" type where mean July temperature exceeds 15.5° C and in which growth is largely influenced by factors outside the growing season.

In Scandinavia the same three types of response can be identified, but for summer temperature investigation it seemed desirable to exclude all trees where the July mean for the standard period 1901/30 exceeds 14° C.

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The three areas considered, named by the author as North Sweden, North Norway, and Trøndelag (N.W. Norway), relate mainly to regions with July means (1901/30) of 12° C, 13° C and 14° C, respectively. Further south the relationship with summer temperature soon becomes ambiguous. In the northern part of the Dalecaria region of south central Sweden the relationship is still positive, but in central and south Dalecaria high summer temperature is harmful to diameter growth.

The author used the arithmetic mean growth (d) of five corrected tree-ring series available in 1950 to calculate an index that gave a good approximation to summer temperatures. The temperature of May to August at Trondheim, t, was related to the mean growth approximately as follows:

$$t \pm 6 = 7(d - 9)$$

where t is measured in tenths of a degree Centigrade and d is measured in tenths of a mm or units of 10I.

Tree-growth in individual years varied from over 1.5 mm in the warm summer 1828 to less than 0.6 mm in the cold summer 1821. Ten seasons in which tree-growth was greater than 1.15 mm generally had temperature departures, at Trondheim, of not less than 2° C above the 1901/30 normal. The nine summers in which tree-growth was less than 0.7 mm were invariably cold. The temperature anomaly of a particular growing-season is often similar over a wide area extending from the Faroes to Finland. Moreover, it can be correlated with the pressure difference between those two regions - more specifically with the extent and strength in North Scandinavia of the "summer monsoon". At this season northerly winds, associated with the Asiatic low pressure system, normally affect West Russia, and spread into Scandinavia for a few weeks, particularly in June. Scandinavian trees provide a very good index of what can be called a "monsoon" summer in Scotland, Holland and northwest Germany.

The 11-year or 22-year sunspot cycle has frequently been "identified" in tree-ring analysis. It is possible that cycles of about 11 years may occur from time to time, and it is only too easy to "detect" such cycles in curves of five-year overlapping means. A cycle that is a true response to a solar cycle should, however, show the same phase-relations from century to century. Utilizing the fact that years of minima are approximately years whose last two digits are divisible by 11 (e.g. 1655, 1666, 1755, 1766, 1833, 1933) a simple test of phase relations of a long index can be made. This test showed that there was no significant relationship between tree ring width and the sunspot cycle.

In Scandinavia there is little information about the weather in earlier centuries but occasionally there are references to the harvests. In northern Finland, Hustich has showed that variations of tree-rings and crops are closely parallel. Crops in the far north depend on summer

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temperatures generally, and often August temperatures in particular; in southern and eastern Sweden hot dry summers can be a disadvantage.

The author pointed out that qualitative features of tree-rings should be considered as well as those that are merely quantitative. For example, the effects of bark scorching through summer heat, the effect of frost in producing a double ring, or the effect of lightning damage or forest fires can often be identified on rings. Dark brownish red portions of wood characteristically formed on the leeward side of conifer stumps could be used to check changes in the prevailing winds. In Alaska, Giddings noted that the timberline tree rings of 1783 were neither particularly wide nor particularly narrow, but they were peculiar in a qualitative sense. The wood of that year failed to deepen to the normal colour of latewood, therein failing to produce a sharp outer boundary, so that in the measurements of some trees the boundary line of 1783-84 was not noticed at all. A ring of this kind is known to tree-ring experts as "faint red". It is hypothesized that this type of ring may be related to the peculiar dust-haze of that particular summer. In May 1783 there were violent eruptions of the volcano Skapter-jokull in Iceland. These eruptions, which culminated in June and July, account for the haze and may explain the "faint red" ring of the Alaskan trees. The author suspected that tree rings in Scandinavia might also have peculiar qualities for the 1783 growing season.

1. SCHWEINGRUBER, F.H.

2. 1980

3. Measurement of densiometric properties of wood.

4. Unpublished pre-circulated paper presented at Dendroclimatology Workshop, Norwich, England, July 7-11, 1980. Unpaged

5. a. Northern hemisphere

   b. Nil

   c. Climatic change (dendrochronology)

6. It is well known that wide and narrow annual rings, and high and low densities occur in wood. Measurement of ring width usually presents no problems, whereas the determination of the different densities within one annual ring was for a long time fraught with difficulties. Until about ten years ago, therefore, research work concentrated on the measurement of ring width and cambial activity. Little attention was paid to cell wall thickness and wood density as an expression of the physiological activity of living cells.

The recently awakened interest in climate oscillations has stimulated a search for relationships between weather, climate, site and growth rings. By measuring densities it is possible to obtain substantial climatic information from trees in boreal and temperate zones but the author stressed that such research has only just begun.

On the basis of previous investigations the following important points have been established: there is a multiple inter-relationship between width and density within one annual ring; ecological information is contained in the density as well as in the width of growth rings. Cell wall growth in late wood (maximum density) is mainly limited, in boreal and subalpine regions, by summer temperatures. Cambial activity, on the other hand, depends on factors affecting the local habitat. In arid zones, cell wall growth and cambial division rate are limited by precipitation; maximum density curves from different tree species synchronize well with each other and maximum density curves are valid over a wide geographical area.

1. SCOTTER, George W.

2. 1961

3. Productivity of arboreal lichens and their possible importance to barren-ground caribou (Rangifer arcticus).

4. IN: Archivum, Societatis Zoologicae Botanicae Fennicae 'Vanamo' 16(2):155-161

5. a. Canada; Index map NO-13; Saskatchewan; B.27

   b. Jack pine, black spruce

   c. Biomass (moss/lichen)

6. This study sought information on the amounts of arboreal lichens occurring in mature black spruce and mature jack pine forests on the winter range of barren-ground caribou in the Black Lake region of northern Saskatchewan. Arboreal lichens on the black spruce and jack pine trees were Alectoria jubata, A. nadvornikiana, A. nidulifera, Cetraria ciliaris, C. pinastri, C. sepincola, Evernia mesomorpha, Parmelia olivacea, P. saxatilis, P. sulcata, Usnea dasypoga, U. glabrescens, and U. hirta. Of these only the fruticose species Alectoria jubata, Evernia mesomorpha, and Usnea hirta were abundant enough to be important forage for barren-ground caribou, with Alectoria jubata of greatest significance.

Arboreal lichens may make substantial contributions to the winter diet of barren-ground caribou, particularly under severe weather conditions. Productivity of these lichens, calculated from data from four trees of each species, ranged from 887 to 1,413 kg/ha in mature black spruce forests, and from 536 to 2,883 kg/ha in mature jack pine forests. The average productivity of arboreal lichens was approximately 704 kg/ha in black spruce forests and approximately 2,050 kg/ha in jack pine forests.

Only part of these lichen loads was available to barren-ground caribou. The largest available portion of lichens was from ground level to 3 m above ground. About 679 kg/ha of arboreal lichens occurred within this area on black spruce forests, while about 380 kg/ha occurred on jack pine forests. Differences in the shape and growth habits of these trees may explain this variation. Small amounts of auditional lichens were available on fallen trees and when dislodged by wind or snow. Lichen loads fluctuated with the age of the stand, tree density, moisture conditions and tree species.

1. SCOTTER, George W.

2. 1971

3. Wildfires in relation to the habitat of barren-ground caribou in the taiga of northern Canada.

4. IN: Proceedings, Annual Tall Timbers Fire Ecology Conference. Tall Timbers Research Station, Tallahassee, Florida. 336 p

5. a. Canada; Index maps NP-11/12, NP-12/13, NO-13, NO-14; District of Mackenzie, Manitoba, Saskatchewan; B.27

   b. Jack pine, black spruce

   c. Biomass (moss/lichen)

6. The winter range of barren-ground caribou is restricted largely to the taiga of northern Canada. The effect of fire on the standing crop of forage usable by caribou in northwestern Manitoba, northern Saskatchewan and on the north and south sides of Great Slave Lake in the Northwest Territories was determined in forest stands from each of the four study areas.

Average air-dried weight of the usable standing crop ranged from 198.4 kg/ha in the 1- to 10-yr class, to 1216.1 kg/ha in the oldest age class. Yields of grass, grass-like plants and forbs were highest in the 1- to 10-yr age class, but never exceeded a few kilograms per hectare in subsequent age classes. Shrub production was low in the first age class, but was reasonably consistent throughout the remaining age classes. The standing crop of lichens increased consistently from 3.3 kg/ha in the youngest age class, to 525.7 kg/ha in the 51- to 75-yr age class. Despite similar use in the oldest age class, the standing crop of usable lichens increased to 812.6 kg/ha. The increase in high-value lichens was more important than the increase in the standing crop of lichens. The high-value group included the so-called "reindeer" lichens, such as Cladonia alpestris, C. mitis and C. rangiferina. Average standing crop of high-value lichens varied from 1.1 kg/ha in the 1- to 10-yr old class to an average of 627.7 kg/ha in the class exceeding 120 yr of age. Moderate-value lichens reached their peak abundance in the oldest age class, and low-value lichens in the 31- to 50-yr age class. Although it varied within each age class, lichen abundance was related to maturity of the forest. Older forests occasionally produced less forage than younger forests because of variations in tree density, soil type, caribou utilization, and other factors.

In northern Saskatchewan, the standing crop of arboreal lichens within 3 m of the ground was estimated at 678.1 kg/ha in mature black spruce and 380.0 kg/ha in mature jack pine. Standing crop on many other segments of the winter range of barren-ground caribou appeared to be lower. Lichens on fallen trees and lichens dislodged by wind or snow from above the 3 m level increased the available amount to some extent.

1. SEAR, C.B. and P.M. KELLY

2. 1980

3. Effects on climate.

4. Nature 285:533-535

5. a. Northern hemisphere

   b. nil

   c. Climate change (hypotheses)

6. There has been much concern in recent years over the possibility that anthropogenic increases in atmospheric carbon dioxide will produce a major climatic change over the next 50 to 100 years. Natural mechanisms, such as the level of dust thrown into the stratosphere by explosive volcanic activity have, however, been held responsible for significant climatic fluctuations in the past, and must also be considered in any attempt to predict the world's future climate.

Volcanic aerosols injected through the tropopause into the stratosphere can remain there for several years. After a few months, under the influence of the stratospheric wind systems, they form a veil which can cover most of a hemisphere and occasionally, after very large eruptions, the whole globe. The spread of a dust veil is dependent on the latitude of injection, the height reached by the dust, the size of the dust particles and the site of the stratospheric circulation during the development of the veil. In general, this circulation tends to restrict veils resulting from northern hemisphere middle and high latitude eruptions to regions north of 30° N, whereas dust from low latitude eruptions, such as those of Krakatau and Agung, tend to spread over the whole globe. In the case of Mount St. Helens, there is a good chance that the dust, although injected into middle latitudes, will spread over a greater latitudinal range than usual. This is because May is the month with the greatest equatorward component of flow in the lower stratosphere.

The amount of solar energy reaching the earth's surface is reduced by a dust veil, as the radiation balance is altered by back scattering, forward scattering and absorption within the dust veil. In the case of large explosive eruptions, these alterations in the energy budget are believed to be sufficient to produce changes in the atmospheric circulation and climate. Estimates of climatic effect of a dust input of Krakataun magnitude indicate that the maximum depression of hemispheric mean surface temperature is around 0.3° C, occurring about three months after the initial input.

A number of empirical and statistical studies have revealed evidence of volcanic effects on climate and the atmospheric circulation. There have been recent suggestions that climatic prediction for more than two years

Continued ...

Sear, C.B. and P.M. Kelly. 1980. Continued

ahead will require forecasts of the general level of global volcanic activity. It has been suggested that the high frequency of explosive eruptions during the 17th century and early 19th century may have been a major cause of the most severe phases of the Little Ice Age and that the general warming of the early 20th century was a result of the reduced level of volcanic activity at that time.

The authors pointed out that many questions remain unanswered. How do the effects of eruptions occurring at different latitudes and at different times of the year differ? What are the spatial patterns of climatic change following individual eruptions and accompanying longer term fluctuations in the frequency of explosive volcanic activity? Finally, how can the effects of an individual eruption be distinguished in the 'noisy' climatic record? The year-to-year variability of climate is such that the effects of any one eruption, unless it is of a very great magnitude, are unlikely to be readily apparent.

One of the major problems in determining the climatic impact of past eruptions has been a lack of firm data. There is insufficient information concerning the amount and composition of the material injected into the stratosphere by previous major eruptions. It is also only in recent years that reliable observations of the mosphere, and particularly the upper layers, have become readily available. The catastrophic eruption of Mount St. Helens affords an important, first opportunity to study in detail the physics, chemistry, meteorology and climatology of the impact of a major middle latitude explosive event.

1. SEILER, Wolfgang and Paul J. CRUTZEN

2. 1980

3. Estimates of gross and net fluxes of carbon between the biosphere and the atmosphere from biomass burning.

4. Climatic Change 2:207-247

5. a. Northern hemisphere

   b. nil

   c. Climate (carbon dioxide levels), Climatic change (hypotheses)

6. This article provides a comprehensive literature review of burning due to shifting agriculture, deforestation due to population increase and colonization, burning in bushland and savannas, and net release of carbon from the biosphere. The author's complete abstract is reproduced in the paragraph below.

> In order to estimate the production of charcoal and the atmospheric emissions of trace gasses volatilized by burning we have estimated the global amounts of biomass which are affected by fires. We have roughly calculated annual gross burning rates ranging between about 5 Pg and 9 Pg (1 Pg = 10^{15} g) of dry matter (2-4 Pg C). In comparison, about 9-17 Pg of above-ground dry matter (4-8 Pg C) is exposed to fires, indicating a worldwide average burning efficiency of about 50%. The production of dead below-ground dry matter varies between 6-9 Pg per year. We have tentatively indicated the possibility of a large production of elemental carbon (0.5-1.7 Pg C/yr) due to the incomplete combustion of biomass to charcoal. This provides a sink for atmospheric CO_2, which would have been particularly important during the past centuries. From meager statistical information and often ill-documented statements in the literature, it is extremely difficult to calculate the net carbon release rates to the atmosphere from the biomass changes which take place, especially in the tropics. All together, we calculate an overall effect of the biosphere on the atmospheric carbon dioxide budget which may range between the possibilities of a net uptake or a net release of about 2 Pg C/yr. The release of CO_2 to the atmosphere by deforestation projects may well be balanced by reforestation and by the production of charcoal. Better information is needed, however, to make these estimates more reliable.

The influence of terrestrial biomass on the atmospheric CO_2 cycle is potentially very large, but difficult to estimate. With about 700 Pg C present in the atmosphere as CO_2, 600 to 1,000 Pg C in the land biota and a worldwide carbon detritus pool estimated by different authors in the range of 700 to 3,000 Pg C, it is clear that shifts in the land biota and detritus pools can result in important changes of CO_2 in the atmosphere.

Continued ...

Experimental greenhouse studies have indicated that, in the absence of other limiting factors, net primary productivity increases with the logarithm of the CO_2 partial pressure in the atmosphere. However, in natural systems competition occurs between plant species, and environmental factors other than changes in CO_2 will take place, so that net primary productivity is much less affected. Additional studies indicate that the life cycle of plants is often shortened in a CO_2-enriched environment, so that net carbon accumulation in the end may be little changed. The available information indicates that there exist major discrepancies in the published net and gross carbon fluxes between the oceans, the biosphere and the atmosphere.

Most calculations of atmospheric CO_2 releases have so far been based on the assumption that the carbon in the biomass which is cleared by deforestation is directly released into the atmosphere as CO_2. Observations by different authors, however, indicate that this is not the case. It is known that approximately 30% of the total biomass is stored in the roots of plants and that this is only partly attacked by fire. Furthermore, only part of the biomass exposed to fires is actually burned. The rest remains as unburned organic matter or as charcoal (graphitic carbon). As graphitic carbon cannot readily be utilized by micro-organisms, the formation of charcoal is equivalent to a sink for atmospheric CO_2 and a source of O_2.

The total amount of biomass, M, burned annually in a biome is approximately given by the equation:

$$M = A \times B \times \alpha \times \beta \text{ [g dry matter per year (g dm/yr)]}$$

where A = total land area burned annually [m^2/yr], B = the average organic matter per unit area in the individual biomes [g dm/m^2], α = fraction of the average above-ground biomass relative to the total average biomass B, and where β = the burning efficiency of the above-ground biomass.

The most uncertain parameters in the equation are the total land area burned annually and the burning efficiencies of the biomass in the individual ecosystems. The average phytomass per unit area and the fraction of the above-ground biomass in the individual ecosystems are better known, but nevertheless are still uncertain.

In a table that summarizes biomass data for major world ecosystems, the following data are presented for the boreal forest:

Area of boreal forest, 12×10^6 km^2
Net primary production of boreal forest, 800 g/m^2/yr
Average biomass of boreal forest, 25 kg/m^2
Partitioning of boreal biomass: Branches, 5%; Trunk, 53%; Roots, 25%; Dead above-ground biomass, 22%; Above-ground biomass, 75%

Continued ...

The given figures do not include dead organic matter and litter. Schlesinger (1977) estimated the total dead surface organic matter as 55 Pg C, with minimum values in the tropics and highest values in the boreal forests. Based on his figures, the total organic matter including the phytomass and the above-ground dead organic matter in the different ecosystems varies in the wide range of 11 to 41 kg dry matter/m^2.

The largest areal biomass density is found in the tropical forests, with an average value of 39 kg of dry matter/m^2, followed by 35 kg of dry matter/m^2 for temperate forests and 25 kg of dry matter/m^2 for boreal forests.

Wildfires are common in boreal forests, which are nearly exclusively located on the North American and Asian continents. Statistical data on burned areas in these forests are available only for Canada where on the average about 0.4×10^6 ha, or 0.1% of the standing boreal forest, are destroyed annually by fires, mainly during springtime. Fire statistics for the Asian continent are completely lacking, but it is likely that the burning rates in these areas are comparable to those observed in Canada. Based on a total area of 12×10^6 km^2 for boreal forests, the annually burned area accounts for 1.0 to 1.5×10^6 ha, containing a total biomass of 250 to 375 Tg of dry matter (1 Tg = 1 terragram = 10^{12} grams). With an average above-ground biomass fraction of 73% and a burning efficiency of 20%, as found in temperate forests, the burned biomass in boreal forests is calculated to be 37 to 55 Tg of dry matter/yr.

For wildfires in boreal forests the authors present the following summary data, with the range shown for each parameter and the average in brackets:

Annually burned and/or cleared area, 1.0 to 1.5 million ha (1.3)
Total biomass cleared annually, 250 to 380 Tg* dry matter** (320)
Biomass annually exposed to fire, 180 to 270 Tg dry matter (230)
Annually burned biomass, 40 to 60 Tg dry matter (50)
Dead below-ground biomass in boreal forests; 70 to 110 Tg of dry matter (90)
Dead unburned above-ground biomass in boreal forests, 140 to 210 Tg of dry matter (180)

* 1 Tg = 10^{12} g
** to convert dry matter to carbon, multiply by 0.45

As shown by the data summarized above, a considerable part of the biomass exposed to fire remains unburned in the field, mainly as dead organic matter and charcoal. Whereas the dead organic matter is gradually decomposed by microbial activity, the charcoal cannot be metabolized in significant amounts by microorganisms and therefore remains in the soil for a long time.

1. SHCHERBAKOV, I.P.

2. 1977

3. Forest vegetation in burned and logged areas of Yakutsk.

4. IN: North American forest lands at latitudes north of 60 degrees. Proceedings of a Symposium. University of Alaska, Fairbanks, Alaska. p. 65-84

5. a. U.S.S.R.

   b. Larch, Scots pine

   c. Climate (precipitation, temperature), Climate/growth (direct relationships), Treeline studies (growth)

6. Yakutia occupies 3.7 million km^2 in the northeast Asian part of the U.S.S.R., between 56° and 76° N and between 108° and 162° E in a region that claims the severest continental climate in the northern hemisphere. Temperature ranges are the largest here: in central Yakutia, for example, the mean temperature in July is 18° C; in January it is -43.4° C. The amplitude of absolute temperatures is 102° C, from +38° C in July to -64° C in January.

The second important climatic factor is precipitation. A vast region of Yakutia, its central and northern region in particular, is arid. The amount of precipitation ranges from 142 to 340 mm/yr; in central Yakutia it is about 200 mm. Only the southern Aldan plateau regions enjoy 350 to 510 mm of annual precipitation, which is caused by the mountainous topography of the area. In summer, as a result of the combinations of intense heat and low precipitation, the vegetation is subjected to most unusual conditions, which cannot be paralleled anywhere in the Soviet Union.

Permafrost plays a major role, particularly in relation to vegetation since it functions to retain moisture in the soil, releasing moisture gradually in summer. This particular function of permafrost in the arid conditions of Yakutia compensates for the low summer precipitation.

The severe climate and limited yearly precipitation, as well as long hours of daylight in summer, contribute to the heavy predominance of species that are both light-loving and cold-resistant. Over 92% of the forests in Yakutia are made up of Dahurian larch (**Larix dahurica**) and Scots pine. Dahurian larch is the most cold-resistant as well as most light-loving among the conifers, preferring clay soils of medium dampness. The northern forest boundary of Yakutia always consists of larches. This can be explained primarily by the continental climate of the area as well as the severity of winter, which the larch can endure because it sheds all of its needles annually.

1. SHPALTE, E.P.

2. 1978

3. Effect of meteorological factors on the radial increment of pine in Latvia.

4. Lesovedenie (1978) 3:11-18

5. a. Latvia

   b. Scots pine

   c. Climate/growth (direct relationships)

6. Indices of variations of ring width were used to study the pattern of increment of **Pinus sylvestris** growing on mineral soils with normal moisture status in Latvia. Over the period 1892 to 1970, there were 31 yr of abnormally great radial increment. The increments for these years were analyzed in relation to a large number of meteorological factors for the period April to August of the previous year and of the current year, and for the whole 17-month period from April of the previous year to August of the current year. Regression equations were derived, and the significance of the various meteorological factors was determined. In the period April to August of the previous year, the most significant factor is the mean temperature in April. In the current year the most important factor is the mean temperature in March. The radial increment of pine was determined mainly by the meteorological factors of the current year.

1. SIMS, R.A. and J.M. STEWART

2. 1981

3. Aerial biomass distribution in an undisturbed and disturbed subarctic bog.

4. Canadian Journal of Botany 59:782-786

5. a. Canada; Index map NN-15; Manitoba; B.22a

   b. Black spruce

   c. Biomass (trees, shrub/herb, moss/lichen)

6. In northern Manitoba peat plateaus are present as widespread raised areas of treed bog. In an undisturbed state, such bog occurs over the low, permafrost-cored plateaus as **Sphagnum** and ericoid-rich peatlands, often with an open and unmerchantable cover of **Picea mariana**. When vegetation is removed, the surface of peat plateaus can remain relatively unvegetated for at least a decade. **Picea mariana** seedlings may not reestablish on the dry peat mounds for 15 years. In this study the authors recorded differences in aerial biomass between an uncleared and cleared portion of a subarctic treed peat plateau at a single site near Gillam, Manitoba.

Total aerial biomass in the treed bog was estimated at 7,939 kg/ha with **Picea mariana** accounting for 28.7% (2,280 kg/ha). **Picea mariana** and the three dominant ericoids **Ledum groenlandicum**, **Chamaedaphne calyculata**, and **Kalmia polifolia** accounted for 78.1% of the aerial biomass. The total live aerial biomass of the wooded plateau was only 28% of the 78,000 kg/ha estimates for northern Eurasian taiga spruce forests (Rodin and Bazilevich 1966).

For the disturbed plot, total aerial biomass was estimated at 2,098 kg/ha, or only 26.4% of the undisturbed plot's biomass. Particularly notable in their ability for recolonization of the dry peats were **Rubus chamaemorus** and **Carex aquatilis**, which together accounted for the majority (90%) of aboveground phytomass other than dwarf shrubs in the cleared area.

For most species common to both areas, biomass was significantly lower in the cleared plot. Dwarf shrubs represented only 44.2% of the biomass in the undisturbed area. Likewise the biomass of herbs, ground lichens, and bryophytes was 57.1, 0.1, and 3.1%, respectively, of that of their undisturbed counterparts. Only the graminoids slightly surpassed the undisturbed area's total biomass by 34 kg/ha (132.7%). **Ledum groenlandicum**, **Chamaedaphne calyculata**, and **Kalmia polifolia** accounted for 49.4% (3,922 kg/ha) of total aerial biomass in the undisturbed area and 82.3% (1,726 kg/ha) in the disturbed area. In the treed area, from 72.0 to 87.7% of the ericoid biomass was held in woody stems, with minor contributions by reproductive organs.

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In the cleared area, the relative quantity of photosynthetic biomass (i.e., leaf plus reproductive tissue) was about 20% greater than in the uncleared area and in the 7 years since vegetation removal, the woody component had not returned to its same proportion. Reproductive effort, as a measure of the current year's reproductive dry weight over the species' total aerial biomass, ranged from 6 to 10.6 times greater in the disturbed than in the undisturbed plot. Above-ground dry weights for plant species on the undisturbed and disturbed portions of the study bog were as follows:

Species	Aerial biomass (kg/ha) Undisturbed	Disturbed
Trees		
Picea mariana	2,280	-
Dwarf shrubs		
Ledum groenlandicum	1,889	562
Chamaedaphne calyculata	1,814	1,097
Kalmia polifolia	219	67
Oxycoccus microcarpus	8	9
Vaccinium vitis-idaea var minus	12	8
Andromeda glaucophylla	-	4
Empetrum nigrum var hermaphroditum	6	-
Herbs		
Rubus chamaemorus	340	190
Smilacina trifolia	5	3
Epilobium angustifolium	-	4
Graminoids		
Carex aquatilis	72	110
Carex chordorhiza	24	3
Eriophorum spissum	8	15
Calamagrostis canadensis	-	10
Ground lichens		
Cladina alpestris	377	-
Cladina rangiferina	370	1
Cladonia amaurocraea	24	-
Icmadophila ericetorum	9	-
Bryophytes		
Sphagnum fuscum	478	6
Polytrichum juniperinum	4	5
Ceratodon purpureus	-	4
Total	7,939	2,098

1. SIRÉN, Gustaf

2. 1970

3. Remarks on current silvicultural research in the subarctic of Finland.

4. IN: Ecology of the Subarctic Regions, Proceedings of the Helsinki symposium. UNESCO, Paris. p 343-348

5. a. Finland

   b. Scots pine

   c. Climate/growth (direct relationships, latitude), Climatic change (dendrochronology), Treeline studies (climate, growth)

6. The standardized series of annual rings available for the regions adjacent to the Fennoscandian forest limit demonstrate that the radial increment of trees has fluctuated markedly. Comparisons of these series with meteorological data for the years 1903 to 1960 led to the conclusion that a low summer temperature retards radial increment, while a high summer temperature for several years results in increased increment and marked flowering and seed-setting, followed by the regeneration of the forest.

The negative aspect of these climatic fluctuations is shown in other ways than by poor radial increment and a failure to set seed. A systematic examination of the areas on each side of the present northern limit of Scots pine shows that large areas beyond this limit were forested, probably even at the end of the sixteenth century. Windfalls from the beginning of the seventeenth century, when the climate - judging by the narrowness of the annual rings - was severe, were without exception very shallow-rooted throughout the area investigated. As late as the sixteenth century, the tree and forest limit in places lay 30 km further north in the districts of Enontekiö, Inari and Utsjoki in northern Lapland, than it does today.

The author suggested that the dominant stress factor at the forest limit is scarcity of energy. Although light conditions at the forest limit are not limiting, the light cannot be utilized because of the low temperatures which prevail even in June. The physiologically significant heat sum is very low. The latter heat sum has been defined as:

$$T_{+5°C} = \sum_{m=1}^{n} (tm-5)$$

where n = number of days with mean temperature over 5° C;
tm = mean temperature of those days; and
+5°C = the threshold value for temperature which permits measureable growth

1. SIRÉN, Gustaf

2. 1979

3. Premises of energy forestry in Sweden.

4. University of Alberta, Edmonton. Forestry Program, Forestry Industry Lecture Series No. 3. 20 p

5. a. Sweden

   b. Willow

   c. Biomass (tree)

6. Of the abiotic requirements for photosynthesis, the macroclimate is on the whole unalterable. On the other hand, a forest farmer with some biological knowledge can influence the microclimate, primarily the degree of solar energy exploitation. In conventional conifer forestry at latitudes 55° N to 70° N, the average conversion of total incoming radiation to harvestable wood is only about 0.15%. This corresponds to 1 thermal kwh/m^2 (= 2.5 t dry matter/ha/yr = 4.5 m^3 solid volume/ha/yr). In young broad-leaved stands, the conversion efficiency is somewhat better; yields in virgin willow stands may reach the magnitude of 10 to 15 m^3 solid volume/ha/yr or about 5 to 6 t dry matter/ha/yr. The low level of present conversion does not depend in the first instance on insufficient supplies of solar energy, carbon dioxide or total precipitation but has, as a rule, other causes. A short, cold growing season is, however, the dominant factor in the interior of northern Sweden.

The author points out that if we could develop a conversion of about 2% of the solar energy available during the growing season it would result in a harvest in the order of 24 to 28 t dry matter/ha. This is ten times greater than in conventional forestry, and the energy quantity converted corresponds to about 10 tonnes oil equivalent/ha/yr.

The selection of willow clones in Sweden has so far resulted in approximately 10 superclones that are expected to produce greater than 20 t dry matter/ha/yr. The best five may reach the level of greater than 25 t dry matter/ha/yr, which corresponds to 10 tonnes oil equivalent/ /ha/yr.

1. SIRÉN, Gustaf and Pentti HARI

2. 1971

3. Coinciding periodicity in recent tree rings and glacial clay sediments.

4. Reports of the Kevo Subarctic Research Station 8:155-157

5. a. Finland, U.S.S.R.

   b. Mil

   c. Climatic change (hypotheses, dendrochronology, proxy data)
   Climatic variation (temporal)

6. Research in dendrochronology has revealed the occurrence of more or less regular fluctuations of tree ring width. The original causes of the periodicities observed seems to be unknown, even if the climate supposedly governs the main pattern of tree growth. The structure of a series of tree rings may additionally be distorted or at least influenced by endogenic, physiological phenomena within trees. There are unanswered questions about the fluctuations because of the short span of the tree ring series collected in Scandinavia. Meteorological data series are short all over the world.

To surmount at least some of these obstacles, this study attempted to replace the tree rings by a similar type of serial material. Postglacial clay sediments offer such a possibility. In principle, these sediment series should reflect climatic changes in the same way as the tree rings of the subarctic region. The periodicity of three time series were studied, tree rings from Lapland, clay sediments from southern Finland and clay sediments from Estonia.

The analysis indicated that in all three series studied, periods of different lengths occurred. Many of these periods coincided in two or three of the three series studied, although with disputable significance in some cases. It is possible that some features in the climatic fluctuation pattern have remained unchanged during the last 12,000 yr. The authors have presented a review of cycles, reflected in the data of this study, and the possible causes. The following cycles have been encountered: 1) The 2.24-yr cycle occurring in both of the clay sediments coincides with the quasibiennial oscillation caused by the changes in movements of the moon; 2) the 11-yr, slightly irregular sunspot cycle is well known from many reviews on cycle research and astrophysics; 3) the weak 13.7-yr cycle may be caused by the influence of the moon; 4) the 22-yr cycle seems to be generated by sunspot activity; 5) the 32-yr cycle probably corresponds to the 33 to 35 yr-cycles mentioned by many authors. No physical explanation is yet available, except the possibility of a multiple of the sunspot cycle; 6) the

Continued ...

indistinct 80 to 96-yr period which has been suggested to be a multiple of the normal sunspot cycle; it may correspond to the 92 to 93-yr cycle proposed previously by the senior author.

The periods indicated by this study seem to be of stationary character. This might indicate the existence of invariable generators of regular climatic oscillations. The above suggested causes of cyclicity do not cover recorded cycles of medium duration, such as those with 2.56, 3.60, 4.3, 6.0 and 7-yr periods.

1. SJÖRS, Hugo

2. 1963

3. Amphi-Atlantic zonation, Nemoral to Arctic.

4. IN: A. Löve and D. Löve, Editors, North Atlantic biota and their history, Symposium Publications Division, Pergamon Press, New York. p. 109-125

5. a. Northern hemisphere

   b. Mil

   c. Climate/growth (direct relationships)

6. This article contains two maps that show zones and subzones of the boreal forest in North America from Manitoba eastwards and in Europe as far eastward as the Ural Mountains. The general similarity of zonation on the two continents is very striking.

The author's analyses revealed two interesting features of boreal zones in relation to climate. First, all zones bend southward when near cold seas such as Hudson Bay, the Atlantic Ocean off Labrador and Newfoundland, and the White Sea. The woodland-tundra in these sectors, and even the subarctic zone near James Bay, is extraordinarily narrow due to this southward depression. The Baltic Sea, although cool in spring, has an opposite effect, presumably because of comparatively long-lasting autumnal warmth. Secondly, when not influenced by the cold sea effect, the width of the zones and subzones is dependent on slope. If the general slope is southern, zones tend to be narrow, with a greater width related to a northward slope. This is an effect of altitude, and shows that such an effect is present not only in mountainous areas. Even moderate elevation has considerable impact on vegetation, a factor that has not always been duly appreciated.

The author stressed that in subzone designation in the boreal forest, length of the growth period appears to be highly important. Growing season is defined as duration of the period when mean temperature is above +5.5° C or 6° C. A lower temperature limit makes cool oceanic areas seem more favourable than they are. Summer heat seems to be more important near and above the treeline than it is further south. Winter cold is not of any general importance, and there is little relation between boreal subzones and the distribution of permafrost.

1. SKYRE, O. and W.C. OECHEL

2. 1979

3. Moss production in a black spruce **Picea mariana** forest with permafrost near Fairbanks, Alaska, as compared with two permafrost-free stands.

4. Holarctic Ecology 2:249-254

5. a. Alaska

   b. Black spruce, White spruce

   c. Biomass (moss/lichen), Climate/growth (microclimate)

6. During the 1975 and 1976 seasons the net primary production of five common bryophytes in a mature black spruce forest near Fairbanks, Alaska was studied to assess energy flow through the ecosystem.

One basic hypothesis is that tree and moss growth is mediated by soil temperature and nutrient content. On oligotrophic sites moss competes with trees and shrubs for available nutrients, and a considerable part of the nutrient pool that would have been available for tree growth could be tied up in the moss layer.

Soil temperature is affected mainly by air temperature and radiation, and may show large variation depending on slope, aspect and tree coverage. The uptake of water in moss usually takes place through the leaves and low solar radiation will therefore tend to decrease transpiration rates and promote moss growth. As a result a thick moss cover will be formed, especially if decomposition rates are low as a result of water logging and low oxygen supply. The rates of decomposition, which are also strongly temperature-dependant, are generally lower in moss litter than in litter from vascular plants. The moss cover prevents absorbed solar heat from being conducted down into the soil, and will therefore tend to decrease soil temperatures and decomposition rates as succession progresses.

Although annual tree production was closely correlated to nutrient content and soil temperature, overall moss production seemed to be promoted by low soil temperatures and low nutrient content, probably because the predominant moss species (**Pleurozium** and **Hylocomium**) are both oligotrophic and moisture-limited.

The high moss production at the white spruce site as compared with the birch site may be explained by the low light intensity at moss level which reduces soil temperature and water loss. The importance of light as a temperature-controlling factor is clearly illustrated by the difference in frequency of direct sunlight and moss production between these two sites. The moss (mostly **Hylocomium**) growing at the birch

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Skyre, O. and W.C. Oechel. 1979. Continued

site was generally found on rotten logs that accumulate moisture and prevent the moss from being covered with litter from trees, while there was a nearly uniform moss cover at the white spruce site.

Overall annual moss production at the black spruce site was about 120 $g/m^2/yr$ or about twice as high as the corresponding annual spruce production. The maximum rates of net photosynthesis at peak season (mid-August) 1976 ranged from 0.6 mg $CO_2/g/hr$ in **Sphagnum** species to 2.7 mg $CO_2/g/hr$ in **Polytrichum commune**. Dark respiration at 15° C varied according to growth, with the highest values (0.7-0.8 mg $CO_2/g/hr$) usually found in **Polytrichum** and **Hylocomium**.

1. SONESSON, M.

2. 1975

3. Treeline dynamics in northern Scandinavia.

4. IN: Proceedings of the circumpolar conference on northern ecology, National Research Council of Canada, Ottawa, p. I-147 - I-153.

5. a. Sweden

   b. Scots pine, white birch

   c. Climate/growth (latitude), Climatic change (proxy data), Treeline studies (climate)

6. The author developed a model that simulates ecosystem structure and climate over the past 9,000 yr based on changes in pollen spectra. The changes in the position of the timberline and structure of the forests are shown by pollen, and considered to be mainly due to climate. Included in this article is a description of the altitudinal timberline of the study area.

In northern Europe there has been an obvious change in the reproductive success and primary production of some species during the past four decades, particularly some tree species, in sites ear their altitudinal and latitudinal limits. In areas where human influence has been slight, climatic change since the beginning of the century is likely to be the only major cause. In the Tornetrask area of northern Sweden, where there is a well developed altitudinal timberline, a marked increase in the growth of forest trees, primarily Scots pine and white birch, has been observed since the 1930's. Below the altitudinal timberline there has been an increase in stand density of the birch and birch-pine forests, and colonization by birch and willow of areas above the present timberline. Climatic changes seem to cause greater changes in growth of trees than in the ground vegetation of the area. There does not seem to be a significant difference between the terrestrial ecosystems immediately below and above altitudinal timberline. The presence or absence of trees seems to be the only difference, although quantitative differences in growth of the individual species are likely to occur.

1. SORENSON, Curtis J., James C. KNOX, James A. LARSEN, and Reid A. BRYSON

2. 1971

3. Paleosols and the forest border in Keewatin, N.W.T.

4. Quaternary Research 1:468-473

5. a. Canada; Index map NP-13/14; District of Keewatin; B.32

   b. Black spruce

   c. Climatic change (hypotheses, proxy data), Treeline studies (climate)

6. The forest border in north central Canada is a major bioclimatic boundary characterized by a rather abrupt change from forest to tundra. It has been suggested that forests may have retreated south of the present position of the forest border and that tundra then occupied areas presently forested. The purpose of this report is to introduce new evidence that the forest border has, in the relatively recent past, retreated at least a short distance southward of its present location.

The mean summer position of the Arctic front can be viewed as a climatic boundary that has maintained a coincident relationship with the forest border throughout the postglacial period. North of this boundary Arctic airmasses predominate, whereas south of this boundary in summer, modified Pacific, Arctic, and indeterminate mixtures of airmasses prevail. Changes in atmospheric circulation patterns have been suggested as inducing displacement of the mean frontal zone and being subsequently responsible for latitudinal shifting of vegetation boundaries. Expansion of the tundra would accompany southward shifts of the Arctic front and, conversely, northward expansion of the boreal forest would follow northward shifts of the mean frontal zone.

Compilation of previously published radiocarbon dates and new dates from south of present treeline reveal a tentative pattern of former forest and tundra distributions relative to modern treeline. Forests migrated north of present treeline following deglaciation and the drainage of ice-dammed lakes about 5800 B.P. The northward encroachment of forest reached Dubawnt Lake and remained until about 3500 B.P., after which there was a climatic shift to cooler drier conditions, during which fires burned the forest and trees were unable to regenerate. The forest boundary retreated at least as far south as Ennadai Lake and then to Kasba Lake by 2940 B.P.

After 2900 B.P., the forests migrated at least as far north as the north end of Ennadai Lake. This northward movement was curtailed and subsequent southward adjustment of the forest/tundra boundary occurred between 2210 and 1810 B.P. The forest had readvanced as far north as

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Dimma Lake, 100 km north of present treeline, by 1100 B.P. and subsequent fires at about 1050 B.P. again accompanied forest retreat to approximately 50 km south of present treeline position to Kasba Lake by 780 B.P. Further southward movement was arrested, and after 800 B.P. return of conditions favorable to forest regeneration has resulted in treeline advancing northward to its present position. Further northward movement does not appear to be taking place at present according to historical and ecological evidence.

Comparisons of the modern forest border with the above range of Late Holocene treeline positions and the apparent inability of trees to regenerate on the present northern margin of the ecotone suggest that existing climatic conditions are nearly as severe as any that have prevailed during the last 5,500 yr.

1. STANEK, W. and D. STATE

2. 1978

3. Equations predicting primary productivity (biomass) of trees, shrubs and lesser vegetation based on current literature.

4. Canadian Forestry Service, Pacific Forest Research Centre, Victoria, Report BC-X-183. 58 p

5. a. Canada; Index maps (all in boreal region); All boreal forest sections in Canada

   b. Aspen, white birch, balsam fir, jack pine, black spruce, white spruce

   c. Biomass (tree)

6. The objective of this study was to compile, from available literature, regression equations for calculation of biomass of forest communities and individual plants (trees, shrubs, lesser vegetation) and their components (leaves, branches by size class, bole, merchantable bole, bark, wood, roots by size classes). Individual regression equations, too detailed to annotate here, were provided for the following tree and shrub species that occur in the boreal forest region in Canada: aspen; white birch; balsam fir; chokecherry; pin cherry; Labrador tea; leatherleaf; jack pine; black spruce; and white spruce.

1. STOCKTON Charles W. and Harold C. FRITTS

2. 1973

3. Long-term reconstruction of water level changes for Lake Athabasca by analysis of tree rings.

4. Water Resources Bulletin, American Water Resources Association 9(5):1006-1027

5. a. Canada: Index map NO-12; Alberta; B.23a

   b. White spruce

   c. Climate/growth (direct relationships, indirect influences), Climatic change (dendrochronology, proxy data)

6. The objective of this study was to calibrate the ring widths of trees from stands in several locations within the Peace-Athabasca Delta with existing records of water levels from Lake Athabasca. If the variance explained in the calibration was sufficiently high, the ring widths could then be used to estimate the water levels of Lake Athabasca prior to existing records.

Two climatic factors - precipitation and temperature - control the water balance in a tree. The water balance affects processes governing manufacture and consumption of food as well as processes of growth. In semiarid regions seasonal variations in both of these climatic factors are reflected in the ring widths of conifers. By contrast, trees near the arctic treeline respond more to temperature before and during the growing season than to available moisture at the site. Because the white spruce in the Peace-Athabasca delta region are not far enough north for their growth processes to be severely limited by low temperature, their ring widths were not expected to reflect temperature variations.

The authors were surprised to find that the widths of rings in the trees from the delta region may vary from year to year so much as they did and that they cross-date so well from site to site. However, the climate of the Peace-Athabasca region is known to be dry as well as cool. It was also noted that white spruce are most vigorous and oldest on well-drained sites at the tops of levees. Trees grow well as long as an active stream is nearby, but if a stream meander is cut off or migrates there appears to be a deterioration in growth in white spruce, and species typical of wetter areas begin to invade the site. This implies that some factor related to the presence of the river - probably water stage - is affecting the growth of white spruce on the natural levees.

The growing season for white spruce was not actually observed, but it probably begins in May or early June and ceases in August or September. Growth is dependent upon the maintenance of favourable water and food balances for the entire photosynthetic period, which may begin in spring

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as soon as needle temperatures remain above freezing, except for short periods at night, and end in autumn when night temperatures drop well below freezing. Growth may cease before the tree stops photosynthesizing, so the conditions of one season can influence the growth of the next season. In addition, excessive moisture and lack of soil oxygen, caused by extensive flooding in one year, can limit root growth and, consequently, the ability of a tree to absorb water the following year. Flooding can also bring nutrients into the ecosystem which favour high growth in the following year. These possibilities merit further investigation, but such an investigation could not be accomplished in the time available for this study.

The authors assumed an empirical linear model in which light or low water at different times in the year can affect the growth for that year and for the following year. It was assumed that trees on individual sites can vary in their soil moisture and aeration characteristics, and the growth period can vary somewhat between sites. Thus, tree growth on poorly drained sites could be inhibited by high water levels and favoured by low levels whereas those on very well-drained sites could be favoured by high water levels and inhibited by low ones. Flooding at different times during the season could affect trees on some sites differently. An early flood could limit growth during that particular growing season but favour growth or have no effect on growth during the next season. A mid-season or late-season flood might have no effect on the concurrent growth but affect growth in the next year. Also, the hydrology of the various waterways might affect the sites of the trees and influence the relationship between growth and levels of the lake.

The growth of trees on different sites was assumed to be linearly related to the levels of Lake Athabasca, but the sign and magnitude of the relationships was allowed to vary both for the season concurrent with and for the season following the lake level occurrence.

The water level of the channels could be correlated with lake levels, therefore it was possible to use the tree ring series to extend the known 33 yr record of lake level changes to 158 yr. By using canonical analysis and 10-day mean lake levels for the three different sub-periods in the 33-yr period of calibration, along with tree ring series from appropriately chosen stands of white spruce, reconstructions were made of the long term record for late May, early July and late September. The reconstructed record shows that the May 21 to 30 lake levels have been three times as variable in the past as in the period of historical record (1935 to 1967), the July 11 to 20 levels twice as variable, and the September 21 to 30 levels 10% less variable. However, the mean water level for each of the three sub-periods for the long term record is very close to the mean water level for the period of historical record.

There are several limitations to the reconstruction techniques. The technique probably tends to average the true response to water levels

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over the entire delta area and consequently give the average water level in the waterway from which the samples were obtained. Under some circumstances, the level of the waterways might not be truly representative of the water level in Lake Athabasca.

There appear to be many similarities between regional climatic variation and the reconstructed record. Although the water level of Lake Athabasca was not expected to respond identically to patterns of climate for such a large region, there were more similarities than dissimilarities to the climatic trends described by Thomas (1965) for the Canadian Prairie region. A few of the most striking similarities are as follows: period 1837 to 1848 - drought in the Prairie Region - low lake levels; period 1860 to 1869, flooding in 1861 and general dry conditions throughout the rest of the decade - high water levels 1860 to 1863 and extremely low levels during the rest of the decade; period 1880 to 1889, a cold period throughout Canada, especially severe winters at Edmonton - high lake levels. Not all lines of climatic evidence noted by Thomas (1965) show such agreement. Several appear to be unrelated to changes in the lake levels, but very few actually contradict. Since steep precipitation and temperature gradients are known to occur across Alberta, it is not too surprising to find cases where differences exist. Thus, it appears that no significant conflict exists between known records of climate and the reconstructed water levels.

1. STRANG, R.M.

2. 1973

3. Succession in unburned subarctic woodlands.

4. Canadian Journal of Forest Research 3:140-143

5. a. Canada; Index map NR-7/8/9; District of Mackenzie; B.23b

   b. Black spruce

   c. Treeline studies (growth)

6. The effects of burning in the boreal and subarctic forests of northern Canada have been discussed by many writers but succession in the absence of fire has been given much less attention.

Preliminary measurements and extensive observations in the uplands of the lower Mackenzie River Valley, N.W.T., between Fort Good Hope and Inuvik, during the summers of 1971 and 1972, suggested that the open Picea forest eventually died out if fire was excluded, to be replaced by an almost tundra-like condition. Data from 15 pairs of adjacent 0.08 ha plots showed marked differences between mature stands and recently burned and currently revegetating stands. Where fire had been excluded for 150 years or more there was a dense growth of lichens, mainly Cetraria nivalis and Cladonia spp, few or no tree seedlings, an open unhealthy Picea stand and a permafrost table close to the soil surface. In recently burned areas, the ground vegetation initially was comprised of the liverwort, Marchantia polymorpha, followed within a few years by herbs, mosses and low ericaceous shrubs and then by a relatively dense and vigorous tree stand. The thickness of the active layer also varied but was always noticeably greater than under dense lichens.

Burning not only deepened the active layer, as is well documented, but it reduced the irregularities in the permafrost table which cause frost heaving. The mean thicknesses of the active layer were 33 and 49 cm in adjoining unburned and burned communities at one site near Eskimo Lake, Inuvik. Because tree seedlings failed to become established in dense lichen mats, it appeared that without fire the stand would disintegrate and disappear. Despite the widespread occurrence of fire, many patches of leaning trees and almost treeless, lichen-covered tracts were noted in the lower Mackenzie Valley. If these areas were to coalesce and become very extensive, rejuvenation would be long delayed because of an absence of seed trees and the very unfavourable seedbed provided by an unbroken ground cover of lichens.

1. STRANG, R.M. and A.H. JOHNSON

2. 1981

3. Fire and climax spruce forests in central Yukon.

4. Arctic 34:60-61

5. a. Canada; Index map NQ-7/8/9; Yukon; B.33

   b. Black spruce, White spruce

   c. Climate/growth (indirect influences), Treeline studies (growth)

6. Observations made during recent studies into fire history of forests in central Yukon suggest that, in the event of long-continued absence of fire, mixed stands of black and white spruce might become mono-specific black spruce stands. It is, however, unlikely that fires will often be absent for the long time periods needed for this change to develop.

In this article the authors describe an upland, open mixed spruce stand found at km 280 along the Dempster Highway (approximately 66° N, 138° W) on a well-drained, dry ridge crest, with no obvious signs of high moisture content permafrost near the surface. Few mature trees were left standing, most having decayed and broken, though identifiable crowns lay on the ground. In the stand, there was no replacement generation for dead or moribund white spruce but each black spruce was being succeeded by a cluster of young black spruce, suggesting an eventual pure black spruce stand unless fire intervenes and sets succession back to an earlier sere. It is, of course, very probable that the area will burn before it is wholly converted to pure black spruce. Indeed, of some 200 sites randomly located along the highway, this was the only one that had escaped burning for so long. This implies that the common mixed spruce stand may, in fact, be a pyric sub-climax.

Conventional ecological thinking depicts succession as trending towards a climax of large biomass, low productivity and considerable species diversity. However, the authors suggest that in the northern boreal forest diversity and biomass seem to decline with advanced age.

1. SWEDA, T. and T. UMEMURA

2. 1979

3. Nagoya University boreal forest survey.

4. IN: T. Sweda and T. Umemura, Editors, Growth of even-aged jack pine stands. Report of Nagoya University boreal forest survey in Canada, 1977. Nagoya University, Department of Forestry, Nagoya, Japan. p. 1-19

5. a. Canada; Index maps NO-12, NP-11/12; Alberta, District of Mackenzie; B.18b, B.23a

   b. Jack pine

   c. Forest growth and yield

6. The objective of this study was to model growth processes of even-aged single-species forest stands in the boreal forest. The authors selected a study area south of Great Slave Lake and sampled pure jack pine stands at Peace Point in Alberta and at Fort Smith and Horseshoe Lake in the Northwest Territories. The three study areas were located between approximately 59 07 N and 60 51 N and from 111 53 W to 115 22 W. Most of this lengthy report consists of mensurational tables that allow reconstruction of stem diameter distribution and the radial stem growth of individual trees in even-aged jack pine stands.

The growing degree-days, defined as the sum of differences between the daily mean temperature above 5° C and the normal of 5° C accumulated for all days in the growing season, is approximately 950° C-days in the study area. The value is slightly less than one third of that for central Japan. The area's mean solar radiation received at the ground in July is about 500 langleys (cal/cm^2)/day, which amounts to nearly twice as much the value for central Japan. The long summer days account for this.

Dominant species within the survey area are jack pine, black spruce and trembling aspen. The favourite habitat of each species seems to be separated fairly distinctively according to soil moisture. Black spruce is common in moist to wet sites, jack pine in dry sites, and trembling aspen somewhere in between. Each species forms single-species even-aged stands after fires, though mixture is also common. Wet sites including muskegs and peat swamps are exclusively occupied by black spruce. In the survey area jack pine is common on dry sandy soil. Of all the species growing in the area, it forms even-aged single-species stands most frequently. Often referred to as a fire species, jack pine is well adapted to forest fires. Old jack pine stands are very uncommon. The initial stem density of over a few hundred thousands per hectare decreases drastically down to several thousands per hectare by the age of 120 yr, as a result of intra-specific competition and repeated ground fires.

1. TAYLOR, Rosalind M.

2. 1981

3. Tree-ring analysis in forest productivity studies: an investigation of growth-climate relationships in the New Forest, Hampshire.

4. Journal of Biogeography 8:293-312

5. a. Great Britain

   b. Pine

   c. Climate/growth (direct relationship), Climatic change (dendrochronology)

6. Most tree-ring work in Britain and continental Europe has focussed on tree-ring analysis as a dating technique and recently for climatic reconstructions. This article related dendroclimatological methods to studies of forest productivity. It does not deal with boreal tree species but the author presents a very detailed list of climatic variables selected for use in dendroclimatic analysis. Those climatic variables are identified in the paragraphs below.

The general finding of this study in southern Britain was that climate strongly influenced growth of both Corsican pine and Douglas fir. Moisture and autumn coldness were key climatic variables. The author concluded that omission of climatic influences from general growth-environment considerations thus might seriously impede understanding of growth restraints. This contradicted the widely held view that climatic variability was unimportant as a growth-influencing factor, for these conifer species, in a small area such as the New Forest.

If a dendroclimatological study is to be scientifically meaningful and practically useful, four important points must be examined: the influence of confounding environmental factors; chronology reliability; representativeness of climatic data; and sensitivity or appropriateness of expression of the climatic variables. The main potentially confounding factors are forest stand management, heavy seed production years, predation and disease. Some workers consider that the effects of seed years and predation in producing narrow rings are more important than climatic influences. Chronology reliability reflects both the general question of sampling in woodland communities and the more specifically dendrochronological problems of age standardization and cross-dating. Variation in standard dimension measures is often high in forest stands.

The availability of reliable and comprehensive long-term climatic records is limited and it is unlikely that a truly 'on the spot' record exists for most ecological studies. Since local climatic differences may significantly influence plant-environment relationships the applicability

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of the long-term record used in dendroclimatological work to the study area must be monitored.

It is important in tree-ring studies to express climatic data in the form most pertinent to tree growth. This point, which was often overlooked in earlier work, is particularly relevant in the moderate climatic regime of Britain. The author suggested that weather extremes and the frequencies of certain weather events and types in relation to growth thresholds are more important than monthly or seasonal means. The precise growth tolerances of any particular species used in tree-ring work will rarely be known but data can be related to thresholds generally applicable in plant physiological studies, such as 0° C and 6.1° C, 43° F.

The author originally selected 93 potentially important climatic variables involving wind, temperature, rainfall and sun or evaporation parameters. Seasonal frequencies of wind data representing the synoptic conditions associated with mildness (westerly winds) and coldness (northeasterly winds) were examined. Seasonal periods reflected the rapid growth phase, April to October, and the minimal growth phase, November to February, with March analysed separately since it is both a key weather month and the month prior to renewed rapid growth. Annual gale frequency was included as an index of wind speed for which no reliable records were available.

For temperature, attention focused on coldness factors for key spring and autumn months; March, April, October and November. These determine the length of the main growing season each year. The author developed coldness indices that represent the frequency of below freezing temperatures weighted by the extreme minimum (°C) for each month. Summer heat intensity was monitored since other researchers had noted the importance of June maximum temperatures. The frequencies of summer maxima above 20° C and 25° C thresholds were used as two indices of general summer warmth. For March, April and May collectively, a more specific early summer heat index was devised. This was based on temperature frequency classes, scored from 1 (maximum less than 0° C) to 8 (maximum above 30° C). The number of days in each class multiplied by the class weighting and summed for the three months gave the final index value for each year. Growing season data relating maximum and minimum temperatures to the 0° C and 6.1° C thresholds were also considered.

Annual, seasonal and monthly rainfall totals were examined but the chief concern was rainfall effectiveness. This was expressed by summer monthly indices and a winter season index calculated as the multiple of the relevant rainfall total and the number of rainy days involved. Evaporation data were derived from sunshine records using an empirical formula. Soil moisture deficit was estimated as the difference between summer rainfall and evaporation totals. Previous year data monitoring soil water replenishment, previous summer warmth, and overall synoptic conditions were also considered.

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The original 93 variables were later reduced to the following climatic variables for use in dendroclimatic analyses:

WIND VARIABLES

- Total easterlies per annum
- Total north-easterlies per annum
- Westerly winds, April-October
- Westerly winds, November-February
- March westerlies
- North-easterly winds, April-October
- North-easterly winds, November-February
- Westerly winds, previous year
- North-easterly winds, previous summer
- Gales per annum

TEMPERATURE VARIABLES

- March cold index
- April cold index
- October cold index
- November cold index
- Days per annum with minima under 0° C
- Days per annum with maxima under 6.1° C
- Length of growing season, days per annum with minima over 6.1° C
- Days per annum with maxima over 20° C
- Early summer heat index
- June maximum
- Days, previous year, maxima over 20° C

RAINFALL VARIABLES

- Annual rainfall, April-March
- March rain index
- April rain index
- May rain index
- June rain index
- July rain index
- September rain index
- October rainfall
- October rainy days
- Previous year's winter rain

SUN AND EVAPORATION VARIABLES

- Total summer evaporation
- April evaporation
- May evaporation
- June evaporation
- July evaporation
- August evaporation
- August sunshine hours
- September sunshine hours
- Soil moisture deficit

1. TEDROW, J.C.F.

2. 1970

3. Soils of the subarctic regions.

4. IN: Ecology of the subarctic regions, Proceedings of the Helsinki Symposium, UNESCO, Paris. p. 189-205

5. a. Northern hemisphere

   b. Nil

   c. Climate/growth (indirect influences)

6. For this review of subarctic soil types, subarctic is defined as the region between the northern boundary of continuous forest and the line marking the northern limit of conifers.

Precipitation in the subarctic regions ranges from 50 to 75 cm per year. In general, throughout all of the subarctic region, including the coastal sectors, precipitation tends to decrease from south to north. Mean July temperature values are also important for delineation of the subarctic regions. Most of the subarctic region in Alaska and Canada falls between the 10 and 15° C July isotherms.

Included in this review is a discussion of regional processes that affect subarctic soil formation. Soils of the subarctic possess few if any properties unique to the region. If a single pedogenic property could be singled out it would be the tendency for a relatively thick organic mat to form under forested conditions. The existence of slowly changing north to south pedogenic gradients within the subarctic regions has been demonstrated by many investigators.

That there is a slowly changing latitudinal process within the subarctic regions of Siberia appears to be fairly well established. The drier aspect of eastern Siberia as compared to the western sectors of Eurasia has been brought out by a number of Russian investigators. Frost processes appear to play a more important part in the soil systems in the eastern U.S.S.R. than in the western sectors. The sod process has been given a prominent place in the Soviet literature and is re gnized as a distinct important process in the northern forest zone. Apparently there has been no attempt by authors outside the Soviet system to recognize this sod process in their classification systems.

1. TERASMAE, J.

2. 1970

3. Review of tree ring studies in Canada - climatic changes, geological applications and future prospects.

4. IN: Smith, J.H.G. and J. Worrall, Editors, Tree-ring analysis with special reference to Northwest America, The University of British Columbia, Faculty of Forestry, Bulletin No. 7, p. 82-85

5. a. Canada; Index maps (all in boreal region), All boreal forest sections in Canada

   b. Nil

   c. Climatic change (dendrochronology, proxy data)

6. The purpose of this literature review was to summarize the different kinds of tree-ring studies made in Canada in the past, evaluate the present needs and application of tree-ring research and outline some of the new potential areas where tree-ring studies could be applied in the future.

Investigation of tree-ring chronologies in the 1940's and 1950's in Canada showed that tree-ring records suitable for dendrochronological and dendroclimatological studies were available in different regions of Canada. Correlation of tree-ring data within each of the regions could be established with proper selection of species and sampling sites. Positive correlations of tree-ring records between different regions did not appear to exist. Climatological interpretations were made difficult by the lack of available weather records, or the lack of data on the physiological response of the species studied to any particular climatic change. Such basic data must be obtained before attempting climatological interpretation.

At the time of this review, the author indicated that the knowledge of other factors affecting tree growth besides climate is quite insufficient. There are too few standard or master chronologies available for the different species in the different regions of Canada. This is a prerequisite for tree dating beyond the tree range of counting rings in living trees. It would be profitable to undertake cooperative investigations in basic tree-ring research by scientists interested in Quaternary geology, forestry and climatology.

A number of applications of dendrochronology studies were listed by the author. These include: altitudinal and latitudinal treeline movements, occurrence of past forest fires, neoglacial end moraines, neotectonic events, shoreline changes, sea level changes, volcanic eruptions, sand dune migration, age of river terraces, rates of shore erosion, age of alluvial fans, soil erosion and development of muskeg.

Continued ...

Terasmae, J. 1970. Continued

The establishment of correlations between tree-ring patterns and ring characteristics and meteorological or climatological parameters is a prerequisite for applied dendrochronology. Where the appropriate correlations have been established, the tree-ring record can be used for interpretation of past climatic changes, including long-term trends, short-term fluctuations and even certain seasonal changes. It is possible to extend climatological records back through time for more than 1,000 yr by using long tree-ring chronologies in selected areas where such chronologies show appropriate climatic sensitivity.

Long dendroclimatological records provide the basis for study of cyclic patterns of climatic changes in the past, and an analysis of these patterns will make it possible to forecast future changes in climate. Another application of dendroclimatology might be in the climatic interpretation of 'floating' tree-ring records obtained from radiocarbon dated fossil trees buried in peat or other deposits. These ring series, compared with modern ones from living trees of the same species, may provide another means for reconstruction of past climatological conditions.

Another useful application of tree-ring series is related to problems of nutrition because forest tree growth is dependent on soil characteristics, and chemical analysis and electron microprobe scanning of tree-rings can establish the presence of nutrient deficiencies. Similar analytical techniques can be used to utilize the tree-ring records in studies related to soil and air pollution.

1. THAMMINCHA, Songkram

2. 1981

3. Climatic variation in radial growth of Scots pine and Norway spruce and its importance in growth estimation.

4. Acta Forestalia Fennica 171, 50 p.

5. a. Finland

   b. Scots pine, Norway spruce

   c. Climate/growth (direct relationships, indirect influences), Climatic change (dendrochronology)

6. Variation in the radial growth of Scots pine and Norway spruce was studied in 10 localities in southern Finland. The aim of the study was to evaluate the relative accuracy of growth estimation based on data from increment borings, in comparison to other methods. The effect of the number of sample trees on the reliability of annual ring indices was also discussed. The author included a brief review of the importance of climatic factors in tree growth studies. Of the climatic factors influencing the growth of forest trees, temperature and precipitation have the greatest effect on diameter growth. The effects of temperature and precipitation vary from locality to locality and also among tree species. This variation is well illustrated by the differences in the widths of annual rings.

In the northern coniferous zone where the amount of rainfall is normally adequate, the growth of trees has been shown to be highly dependent on summer temperatures, other climatic factors being of minor importance. The role of temperature as a growth-limiting factor is also reflected by the smaller number of tree species to be found in the cold climatic zone, as compared to the number in warmer climatic zones where precipitation adopts an increasingly important role.

The range of temperature within which the growth of Scots pine and Norway spruce usually takes place has been studied by a number of researchers. The radial growth patterns of pine and spruce indicate a differing dependence on climate, temperature in particular. The radial growth of spruce is strongly dependent on the temperature during the early summer, while that of pine depends on the temperature during mid and late summer. Although temperature usually has a stronger influence on the radial growth of trees in northern Europe, a firm relationship has occasionally been found between radial growth and precipitation.

It is known that trees grow at different rates on different forest site types. However, some studies have found that the radial growth patterns of spruce growing on different site types, located near to each other, were surprisingly alike, and that the radial growth of spruce at different altitudes was very similar.

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Thammincha, S. 1981. Continued

It has been demonstrated that differences occur in the radial growth of trees at different age classes. Also, the influence of weather on the width of annual rings is more marked in young stands than in old ones. Moreover, the radial growth of pine and spruce in northern Europe varies with longitude, and, for instance, annual ring index series for the same latitude in Finland and Norway have almost no common features.

The factors that most commonly bring about growth variation are stand treatment, especially cutting, and forest fires and other damaging agents, such as storms and insects. On the other hand, climatic variation may also produce results that resemble the effects of those factors. Hence, erroneous deductions can be made in growth studies if the effect of climatic variation is not taken into consideration.

Attention has been paid in Finland to the effect of climatic variation on growth assessments in both the National Forest Inventory and in various growth studies. Moreover, it is of special importance to take the effect of climatic variation into account when comparing the results of forest inventories carried out in different years.

1. **THOMAS, Morley K.**

2. 1975

3. Recent climatic fluctuations in Canada.

4. Environment Canada, Atmospheric Environment Service, Climatological Studies No. 28. 92 pp.

5. a. Canada; Index maps (all in boreal forest region); all boreal forest regions

   b. Nil

   c. Climate (air masses, precipitation, temperature, insolation), Climatic variation (regional, temporal, temperature, precipitation)

6. The purpose of this study was to provide information on climatic fluctuations that have occurred in Canada between 1940 and 1974, although at several stations, especially in northern Canada, regular observations did not commence until some years after 1940. Data used in this report were taken from the official records at surface synoptic observing stations chosen to provide a good geographical coverage of the country. Stations in or near the boreal forest were: Dawson, Whitehorse and Watson Lake in the Yukon; Yellowknife and Fort Smith in the Northwest Territories; Edmonton, Alberta; Thunder Bay and Kapuskasing in Ontario; Nitchequon and Fort Chimo in Quebec; Goose Bay, Labrador; and Gander, Newfoundland. Eleven districts were arbitrarily defined and climatic fluctuations within these districts were described. Climatic trends for each station and some national trends were also described. The climatic parameters discussed were: temperature, precipitation, bright sunshine, cloudiness, snowfall, and atmospheric pressure.

An example of the information available from this study are the temperature trends in the defined "Mackenzie district". Data from observing stations at Coppermine and the airports at Yellowknife and Fort Smith were used for the "Mackenzie district". The very noticeable trends towards lower temperatures that were in evidence in most of the country do not appear in this district. Decadal values dropped by nearly 1° F until the decades centered in the mid-1960's, but rose 0.5° F from that time to the end of the study period.

Decadal means of pressure from nine weather stations in Canada were calculated and plotted. Monthly values of pressure in winter showed much more variability from year to year than comparable summer month values. Some of the correlations noted were as follows. Pressure at Ottawa in January seemed to correlate fairly well with annual precipitation in Ontario and Quebec. There was little apparent correlation between January pressure at Nitchequon and either annual

Continued ...

Thomas, M.K. 1975. Continued

temperature or annual precipitation in the Ungava-Labrador district. The January pressure at Gander appeared to correlate directly with the Atlantic annual temperature trend. At Whitehorse there appeared to be an inverse relationship between January pressure and annual temperature in the Yukon; as pressure rose, temperature fell over the study period. At Fort Smith there appeared to be no definite relationship between pressure and either temperature or precipitation in the "Mackenzie district". Pressure trends in July at the various stations were slight. At Fort Smith over the last ten years of the study, decadal means rose by about 2 mb. This was the largest directional increase noted for pressure trends at the study stations.

Departures from temperature normals between 1960 and 1969 were lower than normal throughout most of Canada. In Ontario and northern British Columbia and portions of the Yukon and Northwest Territories, temperatures were more than 1° F lower in the 1960 to 1969 period than the average over the period from 1941 through 1970. On the other hand much of southern Alberta and southern British Columbia in the west, the Hudson Bay area in central Canada, and the Gulf of St. Lawrence area of eastern Canada, were slightly warmer than normal in the 1960 to 1969 period.

Of the yearly departures from normal, 1972 was the climatologically most unusual throughout all of Canada. Average annual temperatures at all stations were below normal, a most unusual occurrence. The negative anomalies ranged from less than 1° F in the lower Mackenzie River Basin, to 7° F below normal in the southeastern portion of the Northwest Territories and in northern Quebec. Over the entire northeastern third of the country, where weather data have been recorded for 30 to 40 years, 1972 was the coldest year on record. Throughout this area all stations reported below normal temperatures every month of the year.

Temperature trends in the northern hemisphere from the 1890's until 1960 were graphically compared with temperature trends for southern Canada. Although the temperature trend line for southern Canada was not as smooth as that of the entire northern hemisphere, periods of lower and higher temperatures were in parallel. Temperature trends for both the northern hemisphere and for southern Canada declined from the period 1900 to 1910, to reach lows between 1910 and 1920. Temperatures then rose to reach maximums between 1940 and 1945 in the northern hemisphere; two peaks, one about 1940 and the other about 1955, were reached in southern Canada. Since those peaks, there has been a steady temperature decline. The total range of these fluctuations was less than 1.5° F.

1. TIKHOMIROV, B.A.

2. 1963

3. Principal stages of vegetation development in northern U.S.S.R. as related to climatic fluctuations and the activity of man.

4. Canadian Geographer VII(2):55-71

5. a. U.S.S.R.

   b. Nil

   c. Climatic change (proxy data), Climatic variation (temporal), Treeline studies (climate)

6. Vegetation remains in peat deposits provide evidence of expansion of forest into the tundra of northern Siberia in postglacial times. The northern treeline was 2 to 4° north of present treeline during the postglacial thermal maximum.

The author states that the northern treeline has been moving northward in Siberia in response to climatic improvement in recent decades. Evidence to support this theory includes the active reproduction of trees near treeline, a more vigorous growth represented by greater height and girth, the presence of tundra polygons within the forest zone, and northward increases in the ranges of vertebrates that normally inhabit forest sites.

The scarcity and low quality of seeds from far northern trees combined with conditions difficult for their germination and growth, particularly frequent spring frosts, low soil temperatures and shallow depth of summer thaw in permafrost, are important factors in the maintenance of treeless conditions on the tundra. The activities of man have destroyed forests at their northern limits, aiding in the maintenance of treeless tundra. The author suggests that afforestation of the southern tundra in the U.S.S.R. would improve the severe climate.

References describing the northward movement of the treeline in Alaska, northern Canada, Labrador and Scandinavia are cited by the author. These expansions of the forest are believed to be evidence of a general movement of forests into the tundra of the northern hemisphere, rather than purely local advances occurring in widely separate districts.

1. TIKHOMIROV, B.A.

2. 1970

3. Forest limits as the most important biogeographical boundary in the North.

4. IN: Ecology of the subarctic region, Proceedings of the Helsinki Symposium. UNESCO, Paris. p 35-40

5. a. Northern hemisphere

   b. Nil

   c. Climate/growth (direct relationships), Treeline studies (climate)

6. The forest-tundra is a good example of a transitional biogeographic boundary or belt. It represents a zonal natural phenomenon caused by zonal climatic factors. The botanic-geographical correlation of the northern Eurasian and northern American continents, as well as the islands bordering on them, is greatly influenced by the Arctic Ocean ice and the process of its melting.

In the U.S.S.R., the northern treeline runs parallel to the Arctic Ocean coastline, with the northernmost forests on the protruding part of the Taimyr Peninsula (72 40 N). In contrast, in Canada the invasion of cold arctic water and ice into Hudson Bay, as well as the long time during which the ice actually remains in the bay, bring the northern forest limit as far south as 50° N. Thus, the difference between the northern forest limit and the southern tundra limit, amounts to more than 20° of latitude.

In other parts of the world the northern forest limit oscillates from 72 30 N (lower reaches of the Lena River) to 58 55 N (the shore of the Okhotsk Sea). Arctic Ocean ice, the regimes of sea currents governing water temperature, processes of surface water evaporation, and air currents that have their origin in the polar basin, form the complex of factors that influence the location of northern treeline. Among the factors restricting the vitality of trees and limiting their northern boundary, the following are mentioned by the author: mesoclimate and microclimate, permafrost, the initial process of soil formation, biocenotic factors, biology and ecology of trees, and the influence of man and domestic animals.

The author noted that the absence of a dense tree canopy in forest-tundra enables the development of relatively highly productive lichen communities. There are some data showing that fruit productivity by berry shrubs is somewhat higher in the forest tundra than it is in the taiga.

1. TUHKANEN, Sakari

2. 1980

3. Climatic parameters and indices in plant geography.

4. Acta Phytogeographica Suecica 67, Uppsala, 105 p.

5. a. Northern hemisphere

   b. Nil

   c. Climate/growth (direct relationships, latitude)

6. The main purpose of this very detailed review was to relate climatic classification to vegetational classifications. Climatic parameters and indices are applied firstly to polar treeline, which seems to be a boundary that is determined directly by climatic influence, and secondly to vegetation zones and sectors of Fennoscandia. The author also examined equivalent zones in Canada.

A well-known formula is the CVP (climate-vegetation-productivity) index for estimating the productive capacity of forests:

$$CVP = \frac{Tv \times P \times G \times E}{Ta \times 12 \times 100}$$

where Tv = mean temperature (° C) warmest month
Ta = difference in mean temperatures (° C) of warmest and coldest months
P = annual precipitation (mm)
G = growing season, expressed as number of months, counting only those months with a mean monthly temperature equal to or higher than 3° C
E = radiation-evapotranspiration reduction, i.e. $\frac{100 \times R_p}{R_e}$

in which
R_p = radiation at the poles, 10^3 g cal/cm^2/min
R_e = radiation at the latitude under consideration, 10^3 g cal/cm^2/min

The CVP index makes the assumption that forest production increases linearly with rising mean temperatures for the warmest month, increasing precipitation and lengthening of the growing season, and that it declines with distance from the equator. The author suggests that these generalizations are questionable and there is a difference of opinion on whether this index provides a broad indication of productivity.

Continued ...

Grigor'yev, Budyko and other researchers in the U.S.S.R. also developed an index that combines temperature and moisture factors for estimating the productive capacity of plant communities:

$$d = \frac{R}{Lr}$$

where d = index value, with no specified unit of measure
R = total incoming annual solar radiation in Kcal/cm^2/yr
Lr = amount of heat required to evaporate the equivalent of the annual precipitation, with L = annual precipitation (cm) and r = latent heat of water calculated at 540 cal/ml.

Production in the plant community reaches its maximum when the above index value is close to 1, but some researchers have suggested that a lower index value, towards a moisture excess with accompanying high values of R (over 40 kcal/cm^2/year), will increase production significantly.

One much-debated problem in phytogeography concerns the extent to which vegetation is affected by rare extremes of climate, such as exceptionally late frost in spring, early frost in autumn, long periods of drought, or severe frosts that occur before the formation of a snow cover. Average climates described in terms of mean values are highly abstract in character, and for this reason it would seem logical to emphasize the importance of extreme values. The impact of extreme conditions depends on the extent to which the exceptional circumstances deviate from the normal, the length of time they last, and how often they recur. The author concluded that extreme circumstances may bring about temporary alterations in the distribution of individual species, and perhaps even determine the boundaries of their occurrence, but the regional vegetation will be governed in broad outline by the average climatic conditions.

The author presented a map suggesting that the 10° C isotherm for the warmest month could be rejected as an indicator of northern treeline when calculated from the data for the normal period 1931-60, whereas the 11° C isotherm shows a distinctly better fit in the relatively maritime area of eastern Canada, as does the 12° C isotherm in the continental interior. The location of such isotherms varies greatly from year to year, and the average situation described from a normal period of thirty years is an abstraction. The 10° C isotherm for the warmest month of the year, for instance, is found to vary by a distance of 1,000 km over a period of no more than 16 yr. The fluctuations in the isotherms in question here are particularly great in continental parts of Canada, but diminish as one approaches the more oceanic coastal areas.

The author indicated that the northern treeline appears to react to relatively short-term fluctuations in climate. However, a distinction must be made between advancing and retreating treelines. A treeline is

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probably capable of advancing relatively rapidly after an improvement in climate, whereas it is slower to retreat in response to deterioration in the climate, as the trees can live for many hundreds of years without reproducing, or else can reproduce to a limited extent vegetatively, provided the climatic change is not so great to cause fully-grown trees to die.

The author concluded that in Fennoscandia and throughout the boreal zone the observed decline in growing conditions, the drop in biomass production and the impoverishment of the flora as one progresses from south to north must be attributable to the temperature factor. Other Scandinavian investigators also came to the same conclusion. Humidity is commonly regarded as occupying only a secondary role, even though it may be of considerable importance for agriculture.

The most reliable climatic indicators of different boreal vegetation zones appeared to be potential evapotranspiration, length of the growing season and effective temperature sum. The author could not suggest that any one of these was a better or a worse alternative than the others. The isopleths for length of the growing season (1), effective temperature sum (2) and potential evapotranspiration (3) which coincide most closely with the vegetation zone boundaries in Fennoscandia are as follows:

	(1) days	(2) °C	(3) mm
temperate - hemiboreal	205	48	560
hemiboreal - southern boreal	175	42	510
southern boreal - middle boreal	160	35	465
middle boreal - northern boreal	140	28	420
northern boreal - arctic (treeline)	100	15	320

The author concluded that with the exception of Thornthwaite's potential evapotranspiration and moisture index, indices that require very complex mathematical calculations have rarely been used by anyone other than their authors. The reader is cautioned that even a very strong correlation between a climatic isopleth, which is in principle arrived at objectively, and a vegetation boundary, which is generally open to diverse interpretation, does not necessarily imply a causal explanation. The climatic indicators generally provide only hints at the climatic requirements of the vegetation type or species in question.

1. VAN CLEVE, Keith, Richard BARNEY and Robert SCHLENTNER

2. 1981

3. Evidence of temperature control of production and nutrient cycling in two interior Alaska black spruce ecosystems.

4. Canadian Journal of Forest Research 11:258-273

5. a. Alaska

   b. Black spruce

   c. Biomass (tree, shrub/herb, moss/lichen), Climate/growth (indirect influences, microclimate)

6. Cursory field observation across the spectrum of black spruce sites reveals a substantial range of tree sizes and accumulated phytomass within the same age class of forest. Even though this vegetation type occurs on the poorest quality sites, from the standpoint of forest production, the overstory appears to respond to differences in environmental factors. An obvious possibility with regard to control of primary production is the fact that not all sites are characterized by permafrost in the soil profile. Are sites which are soil-frost free during the growing season sufficiently warm to support greater net tree primary production and more rapid nutrient cycling than permafrost-dominated sites?

Temperature controls on productivity were evaluated at two Alaskan sites with differing thermal regimes, both about 32 km west of Fairbanks (64 45 N, 148 51 W). The poorly drained, permafrost site displayed cooler soil temperatures and higher soil moisture content than were encountered on the sample site of a well-drained north slope. Mineral soil nutrient pools were generally largest on the permafrost site. However, low soil temperature acted as a negative feedback control, suppressing soil biological activity, nutrient mineralization, and tree primary production to lower levels on the permafrost-dominated muskeg as compared with the permafrost-free north slope.

A record of air temperature and precipitation at the two study sites indicated that during the June through August growing season mean air temperatures for the north slope site ranged from 1 to 2° C warmer than the muskeg site. Minimum growing season air temperature ranged from 2.7° C to 4° C warmer for the north slope site than the muskeg site, while maximum air temperature showed little difference between sites during the measurement period. Although large yearly variations rendered most temperature differences between the sites statistically nonsignificant, the site differences were consistent within each year and may be biologically important. Precipitation regimes were nearly identical, with an average of only 1 cm per year more precipitation falling on the north slope site than on the muskeg site.

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The distributions of biomass in the north slope and muskeg black spruce ecosystems are summarized in the tables below.

Above-ground biomass (g/m^2), dry weight

	Live trees above ground*	Shrubs*	Mosses	Lichens	Forest floor
North slope site	2,322.8	172.1	366.6	174.3	12,890.1
Muskeg site	1,531.0	147.4	620.3	132.3	8,172.2

* including attached dead branches

Other biomass components (g/m^2), dry weight

	Standing and fallen dead	Tree roots	Total in phytomass	Organic matter in mineral soil	Grand total
North slope site	436.1	1,040.1	17,199.9	29,800	46,999.9
Muskeg site	694.8	1,245.7	12,352.7	35,500	47,852.7

In both ecosystems, the greatest accumulation of organic matter was encountered in the mineral soil and the forest floor constituted the next largest biomass total. Total tree biomass was higher in the north slope ecosystem than in the muskeg ecosystem.

The distribution of biomass in the overstory component of the black spruce ecosystem was as follows:

Biomass components (g/m^2), dry weight

	Foliage	Live branch	Dead branch	Bole	Above-ground total	Roots	Grand total
North slope site	459.2	288.7	179.0	1,395.9	2,322.8	1,040.1	3,362.9
Muskeg site	376.3	198.2	158.8	797.7	1,531.0	1,245.7	2,776.7

The distribution of net accumulated production in tree components emphasized the greater productive capacity of the north slope site which is free of soil permafrost. During approximately the same time period (57 to 62 yr) nearly twice as much bole wood accumulated in trees of the north slope site, 1,396 g/m^2 compared with 798 g/m^2 in the muskeg site.

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Average annual increments in above-ground live tree components for the two ecosystems were as follows:

Average annual increment ($g/m^2/yr$), dry weight

	Foliage	Live branch	Bole	Total increment
North slope site	48.6	13.0	69.9	131.5
Muskeg site	23.4	8.5	39.8	71.7

In addition to the site differences shown in the table above, another difference in tree production was the higher top-to-root biomass ratio on the north slope site (2.2) compared with the muskeg site (1.2).

Compared with other forest vegetation types from temperate and northern latitudes, the black spruce type sampled by the authors is substantially less productive. The difference in annual increments is most marked (14-fold) in comparison with 36-yr-old Douglas fir in western Washington. Compared with Scots pine in central Sweden, the muskeg black spruce produces only about one-fourth of the annual above-ground tree biomass (72 $g/m^2/yr$ compared with 276 $g/m^2/yr$).

Compared with other ecosystems, the black spruce forest floor contains the largest portion of nutrient reserves in the total phytomass. Biomass and mass of chemical elements returned in litterfall in these stands is substantially less than that reported for other circumpolar boreal forest ecosystems. Values for biomass and nutrient flux range up to more than an order of magnitude less than encountered in pine and spruce forests in Sweden and the U.S.S.R.

In these systems probably the most important controlling variable with regard to differences in ecosystem productivity and nutrient cycling was soil temperature. Even though high moisture levels existed, anaerobic conditions were not observed in frequent examination of the root zones at each site, and soils never dried to a level that would induce drought stress or stomatal closure. Soil temperature may be up to 10° C warmer on the north slope compared with the muskeg during the periods of maximum tree growth in June and July. The more rapid increase and generally higher range of soil temperatures on the north slope site was reflected in a more rapid rate of soil thawing.

Because the forest floor is the principal zone for tree rooting, mineralization of organic matter in this compartment may be a critical control for nutrient supply to the trees. It appears that lower rates of

Continued ...

supply of most nutrients may occur from organic matter mineralization on the muskeg compared with the north slope forest floor. The authors suggested that this reduced rate of nutrient supply primarily reflects the impact of lower soil temperature in reducing organic matter mineralization.

The authors' estimates did not consider the requirements of tree root systems and annual uptake by mosses. The bryophytes may constitute the most effective competitors with the overstory for nutrients in black spruce ecosystems. Because mosses constitute more than twice as much, on a relative basis, of the total phytomass on the muskeg site compared with the north-slope site, they undoubtedly retain a larger portion of recycled nutrients in the lowland site. As a result of these considerations, especially in the case of P and K, the overstory in both ecosystems may experience more severe deficiencies of these elements than indicated by the calculations. In fact, if the annual internal recycling of microbes and mosses were accurately known, the calculated excess for mineralized N, Ca, and Mg would probably not exist.

1. VAN CLEVE, Keith and Lareine L. NOONAN

2. 1975

3. Litter fall and nutrient cycling in the forest floor of birch and aspen stands in interior Alaska.

4. Canadian Journal of Forest Research 5:626-639

5. a. Alaska

   b. Aspen, white birch

   c. Biomass (tree)

6. This paper describes measurements of the biomass and selected chemical elements in litter fall from young, intermediate and mature age classes of aspen and white birch in the interior of Alaska, about 40 km northeast of Fairbanks. All the sample stands examined in this study had developed after fire. The following table summarizes the average biomass, dry weight, of the forest floor, and the annual averages over 4 yr of the litter fall (dry weight) for the different age classes of birch and aspen forests.

Species	Age (yr)	Forest floor biomass (g/m^2)	Annual average litter fall (g/m^2)
Aspen	10	508.2	131.2
Aspen	50	3,828.0	218.7
Aspen	120	5,922.6	222.2
Birch	25	2,107.8	263.6
Birch	50	4,390.8	264.6
Birch	120	4,919.5	244.7

For both aspen and white birch, trends in total litter fall and mass of nutrients generally reflected the trends in leaf litter fall. In aspen litter fall, significant increases in average annual deposition of total biomass and mass of nutrients generally occurred with age up to 50 yr. Branch and seed and miscellaneous categories generally showed increased biomass and mass of nutrients up to 120 yr in aspen. For the birch, the greatest biomass of branches and seeds plus miscellaneous litter was encountered at 25 yr. Mass of nutrients in both these categories combined were the same at 25 and 50 yr and generally the same or slightly larger at 120 yr.

1. VAN CLEVE, Keith and Leslie A. VIERECK

2. 1981

3. Forest succession in relation to nutrient cycling in the boreal forest of Alaska.

4. IN: D.C. West, H.H. Shugart and D.B. Botkin, Editors, Forest Succession: Concepts and Application, Springer-Verlag, New York, p. 185-211

5. a. Alaska

   b. Black spruce, white spruce

   c. Biomass (tree, shrub/herb, moss/lichen)

6. The successional sequences described by the authors were located in the central part of Alaska, in the general vicinity of Fairbanks, but the general trends and conclusions derived from the studies were thought by the authors to have broader application to most of the North American taiga.

Successional stages on the Tanana River floodplain were summarized as follows:

Stage	Vegetation type	Age of surface (yr)
I	Bare surface, initial stage	0
II	Bare surface, salt crust	0-1
III	Open shrub	1-2
IV	Closed shrub	2-5
V	Young balsam poplar	5-10
VI	Mature balsam poplar, young white spruce, alder	20-40
VII	Old balsam poplar, young white spruce	80-100
VIII	Mature white spruce	125-175
		200-300

A peak of 20 to 25 kg/m^2 soil organic matter is attained early in stage VI, followed by a slight decline, and then remains at a relatively constant level of approximately 20 kg/m^2 during the mature successional period. The forest floor biomass reaches maximum values of 5 kg/m^2 in mature white spruce stands, a 12-fold increase over early successional stages.

The standing crop of above-ground, live-tree biomass reaches 20 kg/m^2 on productive balsam poplar sites (stage VI). Accumulated above-ground tree biomass in white spruce may reach 22 kg/m^2 at approximately 180 yr, and undoubtedly declines to a lower level in overmature forests. From early successional to mature successional stages, the portion of

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total system organic matter stored in mineral soil declines from a maximum of 100% at time zero to 43% at 180 yr. The remaining 57% is in above-ground, live-plant biomass and forest floor organic matter. Litter fall declines from a peak of 350 g/m^2 in stage V to 250 g/m^2 in stage VI and less than 100 g/m^2 from early to late mature white spruce stages.

Maximum net annual above-ground production, 950 g/m^2, is attained late in stage V and corresponds to the peak in litter fall. Growth rate declines as poplar mortality increases. White spruce, which progressively dominate these alluvial sites, may not attain maximum productivity until later in the mature stages of succession.

Maximum net annual production in the spruce is attained by about 200 yr. This growth rate undoubtedly declines at greater ages and depends on the frequency of flooding and fire. An important new component of these mature ecosystems is moss, whose net annual production may approach 100 g/m^2 or more by 200 yr. The nonvascular plant cover contributes to an increasingly thick forest floor, an effective insulator for mineral soil that promotes a reduction in soil temperature.

Upland white spruce succession after fire progresses through the following seven stages in Alaska:

Stage	Vegetation type	Age of surface (yr)
I	Newly burned stage	0-1
II	Herb-tree seedling stage	2-5
III	Shrub-tree sapling stage	6-25
IV	Dense hardwood stage (birch and aspen)	26-50
V	Mature hardwood stage	51-100
VI	Mixed white spruce-hardwood stage	100-200
VII	Mature white spruce-moss stage	200-250+

For upland white spruce sites the data base is not complete for standing-crop biomass immediately following fire. Observations on fire destruction of white spruce tree and forest floor organic matter, and estimates obtained from black spruce ecosystems, indicate that white spruce above-ground biomass may be reduced by up to one-half during fire. The patchy nature of burn intensity is reflected by the fact that all conditions of forest floor combustion are observed, from complete ashing to light scorching. The effect of fire on soil organic matter content also is not clear at this time. For ecosystems that have not experienced post-fire soil erosion, it appears that soil organic matter content remains fairly constant throughout the entire successional sequence.

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Recovery of white spruce upland systems following fire is rapid, primarily due to sprouting from tree and shrub root systems. Over the entire sequence, soil organic matter storage declines from 94 to 45%, while above-ground storage increases from 6 to 55% of the ecosystem total. The distribution of above-ground standing crop of organic matter undoubtedly shifts in favour of the forest floor in mature white spruce ecosystems because of tree mortality. However, the soil organic matter pool appears to remain constant. Decomposition rates probably decline because of progressively cooler soil temperatures as moss layers accumulate, and therefore incorporation of organic debris into mineral soil approaches minimal levels.

Annual above-ground tree production appears to reach a maximum during stages III and IV. Maximum net annual production approaches 800 g/m^2 then declines to less than half this value (340 g/m^2) early in mature successional stages (VI and VII). The annual productivity of moss in the mature successional stages may approach 100 g/m^2, one third that of white spruce. The authors predict that moss annual production will increase to approximately 200 g/m^2, while tree production will decline to the same level or less in overmature white spruce ecosystems.

For upland black spruce succession the six recognized stages are:

Stage	Vegetation type	Age of surface (yr)
I	Newly burned stage	0-1
II	Herbaceous-young shrub stage	2-5
III	Shrub stage	6-25
IV	Young black spruce stage	26-50
V	Dense black spruce-moss stage	51-100
VI	Mature black spruce-moss stage	100-200

Available data on post-fire standing crops of black spruce biomass on upland sites indicate that above-ground standing crop of trees may be reduced from 10 kg/m^2 to 0.7 kg/m^2 during fire. This impact is associated with effects on the forest floor, which are substantially more variable than those noted for the overstory. The impact of burning ranges from complete ashing of the organic layers to surface scorching of the green moss. The maximum accumulation of forest floor organic debris amounts to nearly 10 kg/m^2 and is approximately equivalent to the standing crop of above-ground tree biomass in late mature successional stages. The amount of surface organic debris accumulated in late mid-successional to early mature stages may be between four and five times that found in live, above-ground tree biomass. The forest floor generally plays a more significant role in biomass and nutrient storage and in maintaining soil temperature control in these ecosystems than in

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Van Cleve, K. and L.A. Viereck. 1981. Continued

floodplain or white spruce upland successional sequences. Substantial, but currently unknown, reduction undoubtedly occurs in tree root-system biomass following fire.

The organic matter content of mineral soil in upland black spruce sites attains values in excess of those measured for other vegetation types. Mineral soil in late mid-successional systems may store up to 80% of system organic matter, while 17% remains in the forest floor and 3% in live above-ground standing biomass. Later, in mature stages, the mineral soil may store 70% of system biomass, while 15% remains in the forest floor and 15% as above-ground standing crop. The fire cycle controls attainment of these levels of biomass accumulation. The authors hypothesize that in the absence of fire vascular plant production will decline and forest floor and mineral soil biomass will remain constant or slowly increase to a higher stable level as bryophyte cover becomes the dominant plant growth form in systems older than 200 yr.

On the basis of current information it appears that maximum tree production in upland black spruce sites is attained early in the mature successional period (stage V). In general, litter fall and above-ground tree production are up to an order of magnitude less than that encountered in floodplain and white spruce successional sequences. Moss annual production (110 to 120 g/m^2) may nearly equal above-ground tree production in mid-successional to late successional stages (V and VI). While tree production is substantially less than that encountered in the other two successional sequences, the combined moss plus above-ground tree annual production of around 200 to 230 g/m^2 approaches the lower limits noted for above-ground tree production in the more productive sequences. The authors predict that vascular plant production will slowly decline prior to the next fire and that moss production may actually exceed that of black spruce which becomes increasingly senescent.

In summary, as primary or secondary succession progresses, organic matter accumulates both in the standing crop of trees and shrubs and in forest-floor organic debris. The latter "pool" acts as an effective insulating blanket, cooling the mineral soil as forest floor biomass accumulates. Reduced soil and forest floor temperatures slow the decomposition rate, promoting organic matter accumulation. On the average, for each centimetre increase in forest floor thickness, the authors have found approximately a 37° C decline in heat sum accumulated above 0° C at the 10 cm depth between 20 May and 10 September. With advancing succession, a higher forest floor moisture content is reflected in the establishment and increased productivity of bryophytes. At any time, and depending on the severity of the disturbance, fire or flooding may act to set the system to an earlier stage in succession. Coming late in succession, fire acts as a rapid decomposer, replenishing reservoirs of some nutrients (P, base elements) and depleting supplies of others (N), and the change in surface albedo is associated with a marked warming of mineral soil and increase in thickness of the active layer on permafrost-dominated sites.

1. **VAN CLEVE, Keith, Michael WEBER, Leslie A. VIERECK and C.T. DYRNESS**

2. 1979

3. Woodland nutrient cycling: an important consideration in renewable resource management.

4. Agroborealis 11:43-47

5. a. Alaska

   b. Balsam poplar, black spruce, paper birch, white spruce

   c. Biomass (tree, moss/lichen), Climate/growth (direct relationships)

6. This article describes in general terms some aspects of nutrient cycling in forested ecosystems of Alaska, where forest productivity is strongly related to topography. The most productive forest ecosystems tend to occur on warmer soils often with a southern aspect while the less productive ecosystems tend to occur on cold soils. Soil temperature appears to be related to moss production. Black spruce forests have a high level of moss production compared to other forest types. The depth of organic matter in the forest floor is greatest in those ecosystems that display the lowest tree production. During a given period of forest development, balsam poplar, paper birch and white spruce may produce four to seven times more tree biomass above ground than black spruce.

In 60 yr, a paper birch forest may accumulate approximately four to five times more tree biomass than a black spruce forest in the same time period. In contrast, 22% more organic matter may accumulate in the mineral soil and forest floor of black spruce forests compared with birch forests. The moss component of black spruce forests, which accounts for up to 6% of the accumulated net dry matter production, is not an important component of the more productive birch forests. On a unit area basis, annual moss production in black spruce forests may be equal to or greater than tree production.

1. VIERECK, Leslie A.

2. 1973

3. Wildfire in the taiga of Alaska.

4. Quaternary Research 3:465-495

5. a. Alaska

   b. Black spruce, white spruce

   c. Climate/growth (indirect influences)

6. The taiga of Alaska consists of a vegetation mosaic resulting primarily from past wildfires. Both lightning fires and those of human origin burn an average of 400,000 ha annually, creating vast areas of successional ecosystems. Although the number of reported fires is increasing, fire control is becoming more effective in limiting the average size of fires and the total area burned. One of the most important influences of fire in the taiga ecosystem is its effect on permafrost and the soil nutrient cycle. Fire has always been a part of the Alaskan taiga ecosystem: if it is totally excluded from the environment some major ecological changes will result.

Most of the taiga of Alaska lies within a zone dominated by continental climatic influences, characterized by temperature extremes and low precipitation. Large fluctuations from the mean are common. At Fort Yukon in the centre of the Yukon Basin, temperature extremes range from -59° C to +37° C. Within the taiga region, daylight ranges from 20 to 24 hr in the summer months to 0 to 4 hr during the winter. Mean annual temperatures range from -10° C in the northern portions to +2° C in the southwestern regions. Precipitation over most of the area is light, ranging from 165 mm at Fort Yukon in the interior to 750 mm at Illiamna, in the wet southwest portion. The ground is covered by snow from mid-October to mid- or late May, but snow accumulation is relatively light, ranging from 75 cm in the Yukon Basin to as much as 250 cm in the coastal areas.

According to Thornthwaite's evapotranspiration system, most of the taiga falls within zones having a potential evapotranspiration of 356 to 457 mm, with a "typical" interior Alaska climate of DC'$_2$dc"$_2$, i.e., semiarid, warm microthermal with little or no rainfall surplus and with temperature efficiency normal to warm microthermal.

During the period of 1898 to 1940 an estimated 405,000 ha of the taiga were burned annually. It has been suggested that this estimate was too low and that an average of from 0.6 to 1.0 million ha were burned each year between 1900 and 1940. For the period 1940 to 1969 the average annual burn was approximately 400,000 ha. During this latter 30 yr period, over 70% of the fires were caused by man, the rest by lightning. Lightning fires were responsible for 78% of the total area burned.

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With the exception of a few isolated stands, most of interior Alaska has been estimated to have been burned over in the last 200 to 250 yr. The following is an estimate of the areas of different vegetation types burned in the taiga of Alaska from 1900 to 1961.

Type	Area (millions of hectares)	Percentage of Alaska's total burned area
Conifer	7.9	35.9
Conifer-broadleaf	3.3	15.0
Broadleaf	0.4	1.8
Tundra	9.4	42.7
Other types	1.0	4.6
Total	22.0	100.0

The special significance of these figures is that, of the total estimate of 22 million ha burned, 47.3% is in the two treeless classification groups. A detailed study of several burns found that less than 0.5% of the cover burned was classified as commercial forest land capable of producing at least 1.4 m^3 of wood/ha/yr. Fires in Alaska are primarily in tundra, bog and noncommercial forest sites.

The author noted a relationship between bad fire years and increased seed crop of white spruce the following year. One factor of importance in initiation of flower buds in white spruce is a warm dry period in June and the first half of July. These same conditions create high fire danger potential. High levels of seed production would enable establishment on burned areas and ensure the long term presence of white spruce. The author noted that there are many factors involved and further study is required. Another aspect of seed crop periodicity that has been documented for white spruce and may also be important for other species is the production of good cone crops containing poor seed. Apparently the seed fails to mature because of climatic conditions. In interior Alaska in 1970, stands of white spruce from 370 to 430 m in elevation had excellent cone crops but a very low percentage of viable seed.

Destruction of the organic layers at the soil surface will vary with the intensity of the fire. Species that have the ability to reproduce vegetatively after a fire will also be affected by the intensity of fire. In aspen stands most of the propagating roots occur within 5 to 15 cm of the soil surface. In white and black spruce forests, the roots and rhizomes of many of the shrub and herbaceous species occur within 2 to 5 cm of the interface between mineral soil and organic matter. The intensity and depth of burn may cause sprouting and suckering under some conditions and prohibit them under others.

1. VIERECK, Leslie A.

2. 1975

3. Forest ecology of the Alaska taiga.

4. IN: Proceedings of the circumpolar conference on northern ecology, National Research Council of Canada, Ottawa, p. I-1 - I-22.

5. a. Alaska

   b. White spruce

   c. Climate/growth (latitude), Growing season (degree-day totals), Treeline studies (climate)

6. Included in this paper is a review of previous attempts to delineate the zonal boundaries of the taiga in Alaska by climatic parameters. One difficulty is the presence of high mountain barriers in the areas where one would expect zonal boundaries to occur. The presence of the Brooks Range and the Alaska Range break up the general north to south climatic zones and create a continental climate in the interior of Alaska. Earlier attempts to link the treeline boundary of the taiga and tundra with the 10° C July isotherm or the Nordenskjöld line do not accurately depict the situation in western Alaska where a broad band of tundra covers the areas where the climatic indicators would imply that forests should be present. A third main factor complicating zonation in Alaska is the large river systems, which tend to extend the forest environment to the west along the Kobuk and Yukon rivers and to the southwest along the Kuskokwim River.

There have been two attempts to use degree-day summations as a means of delineating the taiga of Alaska. Based on temperature summations above 10° C it was possible to separate tundra from taiga in most cases. The dividing line was roughly at 56° C degree-days and below for tundra and 56° C degree-days and above for taiga. Taiga stations at the edge of the forest in southwest Alaska had up to 167° C degree-day summations. To separate the interior taiga from the coastal Sitka spruce forests an additional factor, temperature of the coldest month, was used. A base of 43° F was also used to calculate degree-days for Alaska taiga stations. The degree-day summations ranged from 944° F in the warmest locations to approximately 555° F at the outer fringes of the forested area.

If the above temperature summation data were placed on a map, they would show that any zonation of the Alaska taiga will not be from a south to north direction but rather in a semicircular pattern, with the most productive closed forests expected in the eastern and central interior along the Tanana and Yukon rivers and with a predominance of open, more slow growing forests to the north, west and southwest. The same semicircular pattern has been shown for mean net radiation in Alaska. The average site index for white spruce is greatest in the central and eastern interior and declines in a pattern similar to temperature summation and mean net radiation.

1. VIERECK, Leslie A.

2. 1979

3. Characteristics of treeline plant communities in Alaska.

4. Holarctic Ecology 2:228-238

5. a. Alaska

   b. White spruce, black spruce, balsam poplar, paper birch

   c. Climate/growth (direct relationships, indirect influences, latitude), Climatic change (dendrochronology, proxy data), Climatic variation (regional, temporal), Growing season (degree-day totals)

6. The treeline in Alaska is usually mapped as the limit of white spruce along the south slope of the Brooks Range and in western Alaska. In some localities black spruce is a component of the treeline community along with white spruce. Of special interest are the groves of balsam poplar that occur on the north slope of the Brooks Range and to the west and southwest of the spruce treeline. There is some question as to whether trees survived in unglaciated portions of Alaska during the last glacial period. Spruce trees became prevalent about 10,000 yr ago and may still be expanding to their climatic limits.

At about 10,000 BP there was a dramatic warming that caused a change in the vegetation of Alaska. It appears that the maximum warm period was not synchronous over all of Alaska but that it may have been at any time between 8,000 and 3,000 BP. Tree stumps and logs have been found in locations 50 km north of present treeline and up to 76 m above the present altitudinal timberline.

After the Hypsithermal period, there was a cooling period with a number of warmer and cooler oscillations, including the Little Ice Age which is recorded by glacial maximums varying from 350 BP to the present. Although the glacial evidence for this cooler period was widespread, there is little evidence from pollen samples or from fossil trees of any significant changes in treeline to more retracted positions. For the Seward Peninsula, investigators suggested that the treeline seemed to have been stable for many centuries. The treeline on the Firth River in northeastern Alaska appears to be in equilibrium with the climate because there is no evidence of regeneration or of degeneration at treeline. Trees at treeline in the eastern end of the Alaska Range were at least 240 yr old and thus date back into the Little Ice Age for that area. Treeline at Eagle Summit in interior Alaska has been stable during the last 700 yr except for an advance in the past few decades.

This recent change in treeline has been noted in several locations in Alaska and seems to be related to a recent increase in mean summer

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temperatures. Vigorous growth of white spruce seedlings as much as 30 km beyond the last forest outliers has recently been noted on the Seward Peninsula. Alder, balsam poplar and willows are also extending their ranges. There has been an active expansion of altitudinal treeline by many young trees less than 40 yr of age in the Tanana-Yukon uplands in the vicinity of Fairbanks. This phenomenon has also been observed in the Alaska Range. It has been reported that the period since 1932 has had above average summer temperatures in Alaska.

Using 43° F as a base, degree-days for Alaskan taiga stations have been calculated. The degree-day summations range from 944 degree-days in the warmest locations to approximately 555 degree-days at the outer fringes of the forested area. The regeneration capability of spruce is probably the factor most significantly affected by temperature. Even in the warmest parts of interior Alaska, seed years for white spruce are infrequent. A large percentage of a year's seed crop may be destroyed by an unusual cold period during early summer. Even in excellent seed years at lowland sites, many seeds have immature embryos. White spruce embryos in interior Alaska reach full size at a temperature summation of about 625 degree-days based on 5° C. In summary, temperature may not be limiting to vegetative growth at treeline but might limit regeneration and the capability of trees to reproduce and expand their range.

Fire is another factor that limits treeline. There is evidence from Canada and the U.S.S.R. of the fire destruction of forest and its replacement by tundra due to inability of tree species to regenerate. No studies have been conducted in Alaska that would indicate whether fires have been important in determining the location of treeline.

Trees at the northern, western and interior treelines of Alaska show little effect from wind. In general, wind effects are less conspicuous at treeline in coastal Alaska than in Norway. In Scandinavia it has been suggested that insects have also played a role in modifying the location of treeline. Almost all of 600 km^2 of former birch forest in Norway have already been turned into treeless tundra because of insect damage. In Alaska there is no account of insect epidemics in treeline areas. However, there have been extensive epidemics of the spruce bark beetle in white spruce areas near treeline communities. If similar outbreaks ever occurred at treeline, they could possibly alter the environment sufficiently to prevent reforestation and thus cause a permanent change in the location of treeline.

1. VIERECK, Leslie A. and Linda A. SCHANDELMEIER

2. 1980

3. Effects of fire in Alaska and adjacent Canada - a literature review.

4. U.S. Department of the Interior, Bureau of Land Management, Anchorage, Alaska. BLM-Alaska Technical Report 6. 124 p.

5. a. Canada, Alaska, U.S.S.R.; Index maps (all in boreal region); All boreal forest sections in Canada

   b. Black spruce, white spruce, jack pine

   c. Biomass (tree, shrub/herb, moss/lichen), Climate/growth (indirect influences), Climatic variation (regional), Treeline studies (climate)

6. Included in this literature review are discussions of fire regime in the taiga, the effects of fire on taiga ecosystems and processes, and the relationship between treeline and fire.

The natural fire regime of the Alaska taiga involves relatively high-intensity crown fires or severe surface fires that kill and regenerate entire stands. The return interval is about 50 to 200 yr. Estimates of 130 yr for open spruce-lichen forest and 100 yr for closed black spruce have been made. The shortest fire cycles occur in interior Alaska and the Yukon Basin and longer fire cycles are typical of western and southwestern Alaska. The natural fire cycle has been estimated to be 49 yr in the 3.6 million ha Porcupine River area. For the following cover types, fire cycles were estimated individually: white spruce, 59.1 yr; black spruce, 58.9 yr; and deciduous tree stands, 28.6 yr. The ecologically significant fires are large, generally 25,000 to 50,000 ha or larger.

In the Mackenzie Valley, fire cycles are between 80 and 90 yr for black spruce types, 30 to 70 yr for jack pine types, and 300 yr for alluvial white spruce stands, many of which are on islands and thus protected from fire. An approximately 100-yr cycle for spruce types in northern British Columbia has been described.

Because precipitation increases from western to eastern Canada, the length of the natural fire cycle should increase from west to east. No estimate of the fire cycle was available from the northern forested areas of Canada, but in New Brunswick fire cycles of 230 yr have been calculated for the red spruce-hemlock-pine type and more than 1,000 yr for the high-elevation conifer types.

In Newfoundland over the past 60 yr, 15% of the commercial forest and 12.5% of the total land area have burned. This gives a fire cycle of approximately 400 yr for forested areas and 480 yr for the total land area. It is emphasized that this is not a natural fire regime and

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involves many man-caused fires. These figures from eastern Canada indicate that the natural fire cycle is much greater in the wetter regions of the boreal forest than it is in the drier western areas of western Canada and central Alaska.

Changes in biomass and productivity in black spruce forests following fires in Alaska are described as follows. Just prior to fire in the black spruce type, the overstory and forest floor biomass are high, but the available nutrient pool is relatively low because most of the available nutrients are tied up in the surface organic layers and overstory. Decomposition is slow - about 2% of the organic matter in the forest decays each year. Soil temperatures during the growing season are low, about 3 to 6° C at 10 cm. Permafrost is as close as 30 cm below the surface and the active layer of annual thawing is entirely within the organic layer. Because of impervious permafrost, the continued slow melt of ice in the active layer during the summer, and the high water-holding capacity of the mosses and organic layer, the amount of moisture is high throughout the summer at depths of 10 cm and deeper. In the organic layer, the amount of moisture by weight remains well above 100%.

Following fire, all of these components are changed drastically. The overstory biomass is greatly reduced by fire, although standing dead trees may persist for up to 60 yr. The biggest effect is in the forest floor, which is partially or completely removed by fire. Burning of forest floor material immediately releases large quantities of available nutrients. For example, as much as 50 times the mass of phosphorus before the fire was available following an experimental burn in a 70-yr-old black spruce stand in Alaska. Nitrogen, on the other hand, may be volatilized by fire, and quantities of available nitrogen may be reduced from those before the fire.

Soil temperatures become warmer and the permafrost layer recedes after fire because of several factors. These include removal of the overstory, change in albedo, thinning of the organic layer, and death of the moss layer. One of the most significant changes brought about by the increase in soil temperature after fire is a thickening of the active layer. The depth of thaw may be two to three times greater following fire than it was before the burn.

For the first few years following fire, nutrient turnover is rapid and productivity is high. With more nutrients available, herbs and shrubs grow rapidly. The pioneering bryophytes, especially **Marchantia**, and the herbs, **Epilobium angustifolium** and **Calamagrostis canadensis**, take up the available nutrients immediately following fire and recycle them quickly through their dead and decaying plant parts. Productivity is high because of the warmer soil and the increased nutrients. These species, which have high relative nutrient requirements and rapid growth rates, have an advantage over other species in the early stages of

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succession but compete less successfully in the nutrient-poor later successional stages. Decomposition rates also are relatively high during this period.

Few data are available to compare the productivity of burned and unburned black spruce stands in Alaska and northern Canada. Studies in Alaska indicated that three to seven years after a fire, the amount of willow browse available to moose increased from 6.5 to 44.1 kg/ha, while in adjacent unburned stands, the available browse was less than 10 kg/ha. This study took into account only **Salix** spp available to moose but gave an indication of the increased productivity of the shrub layer following fire.

Total biomass accumulations for the first four years following the Wickersham Dome fire in Alaska were approximately 160 g/m^2, giving an average annual accumulation of 40 $g/m^2/yr$. Biomass accumulations five years following the Inuvik fire totalled approximately 200 g/m^2, for an average annual accumulation of 40 $g/m^2/yr$. From biomass measurements in a 130-yr-old black spruce stand, the annual foliage production has been estimated to be 24 $g/m^2/yr$, while the total annual above-ground tree production was 168 $g/m^2/yr$ and productivity of the moss layer in the same stand has been shown to be 125 $g/m^2/yr$ or about five times that of the tree foliage production. In young recently burned stands, most of the productivity is in the herb and shrub species; in mature stands, most of the productivity is in the tree and moss layers.

As time passes following fire, the biomass and productivity of mosses and lichens increase faster than those of the vascular plants. This is especially true once the feathermosses become widespread. As mentioned above, on a unit area basis annual production in the moss layer may be nearly as great as that of the tree layer.

Forest floor biomass increases greatly once the tree canopy is established and the feathermosses are abundant. Equilibrium may be reached between decomposition and accumulation in the forest floor in some sites; but on most of the cooler, moister sites, the forest floor continues to thicken and accumulate material. The criterion for a climax ecosystem - that net increment of biomass should equal zero - is not attained. As the forest floor thickens, it accumulates nutrients that are no longer available in the ecosystem nutrient pool. The mature black spruce ecosystem is considered to be a nutrient-poor system that holds tightly to its nutrients. One indication of this is that black spruce may retain their needles for up to 25 yr.

In addition to acting as a nutrient sink, the thickening forest floor acts as an increasingly efficient insulating layer. Soil temperatures become lower as the moss layer thickens and shade from the tree and shrub canopy increases. Soil moisture also increases as the permafrost rises and the water-retaining organic layer develops. These conditions all

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Viereck, L.A. and L.A. Schandelmeier. 1980. Continued

contribute to development of typical less productive, nutrient-poor, black spruce ecosystems that have a thick organic layer closely underlain by permafrost. At this point, or earlier in the successional sequence, the forest usually burns, returning nutrients to the available form and once again increasing site productivity. Thus, fire in this type of ecosystem returns the site to a more productive condition and partially substitutes for the reduced decomposition rate.

In long absence of fire, it is hypothesized that the forest floor would continue to thicken, further tying up nutrients. Moss and lichen productivity would continue to increase compared with that of the tree overstory, and the overstory would become more open and less productive. Soil temperatures would continue to decrease and soil moisture increase, creating conditions that encourage the development of sphagnum mosses over feathermosses. This condition could eventually result in paludification of the site and the development of treeless bogs. Fire is thus an essential ecosystem process that maintains the permafrost-dominated spruce/feathermoss ecosystem. The black spruce ecosystem supports the concept that most forest ecosystems change in patches of various sizes. This change is controlled by intrinsic factors of the ecosystem or by extrinsic factors of the environment. In the black spruce ecosystem, fire serves to recycle the vegetation before it reaches the steady-state climax condition.

Fires at the northern limits of trees in Siberia are thought to result in the permanent displacement of treeline to the south. The tundra that results from these fires has been termed "pyrogenic tundra". The cause of treeline displacement was suggested to be the heavy post-fire vegetation cover that reduced the depth of annual thaw, resulting in colder soils and increased soil moisture to the level that trees could no longer grow on these sites. The same type of phenomenon has been observed in Canada. The retreat of treeline in Canada is generally thought to be the result of climatic deterioration, but fire also has been important. It has been found that periods of extensive fires destroyed trees over large areas of treeline and that trees were unable to reinvade the tundra-like vegetation that formed after the fires. Forests in Keewatin failed to regenerate after fires 3,500 and 900 yr ago and the treeline retreated as much as 280 km. No studies have been conducted in Alaska to indicate whether or not fires have been important in determining the location of treeline. Whereas fire might be instrumental in restricting treeline by killing trees at their limits, tundra fires near the treeline might provide a favourable seedbed for tree seeds and aid in the expansion of treeline during favourable climatic periods.

1. VOWINCKEL, T., W.C. OECHEL and W.G. BOLL

2. 1975

3. The effect of climate on the photosynthesis of Picea mariana at the subarctic tree line. 1. Field measurements.

4. Canadian Journal of Botany 53:604-620

5. a. Canada; Index map NN-19; Quebec; B.13a

   b. Black spruce

   c. Climate/growth (direct relationships), Growing season (degree-day totals), Treeline studies (climate, growth)

6. Field measurements of the diurnal rate of photosynthesis of black spruce, the dominant tree species at treeline, were made at Schefferville, Quebec (55 00 N, 64 00 W). Maximum photosynthesis rates varied between 2.0 and 3.8 mg CO_2/g dry wt/hr, with an overall mean of 2.75 mg CO_2/g dry wt/hr. The overriding limiting factor seemed to be light intensity during the summer months. Air temperature did not significantly limit photosynthesis during June, July and August. No seasonal variations in photosynthesis over June, July and August were observed.

The results of this study indicated that the photosynthetic responses of black spruce are physiologically adaptive to the cool summers and severe winters of subarctic areas. The measured maximum rates of photosynthesis are considerably lower than rates in more temperate areas. The temperature optimum for photosynthesis is between 13 and 15° C, reflecting the cool summer temperature rates. Rates of 30% of maximum photosynthesis were recorded at 0° C. Light saturation for photosynthesis occurred at 0.75 ly/min. This relatively high light saturation level indicates that diurnal photosynthetic accumulation is often limited by light intensity during the summer months, whereas temperature seems unimportant in limiting diurnal photosynthesis during these months. The existence of an open lichen woodland mat maintains soil water potential at high levels throughout the summer. No differences in optimal photosynthesis rates were measured between the three sites used during this study.

The authors cite measurements of maximum net photosynthesis of 0.6 mg CO_2/g dry wt/hr in Scots pine at the subarctic treeline, 70 00 N, in Finnish Lapland. These rates are considerably lower than those of the experiment described in this paper. Rates of between 5 and 8 mg CO_2/g dry wt/hr have been measured for mature conifer trees growing naturally in more temperate areas.

1. **WALTER, Heinrich**

2. 1968

3. Die vegetation der erde in öko-physiologischer Betrachtung. Band II. Die gemässigten und arktischen Zonen.

4. Gustav Fischer Verlag, Stuttgart, 1001 p

5. a. U.S.S.R.

   b. Larch, Scots pine, spruce

   c. Biomass (tree, shrub/herb, moss/lichen)

6. Within this text are several tables that give biomass and productivity estimates of forest types in the U.S.S.R. Distribution of phytomass for coniferous forest types was given as follows.

		Phytomass components (t/ha), dry weight				
Type of stand	Age (yrs)	Tree leaves	Tree wood	Tree roots	Herb & moss layers	Total
Forest tundra, abundant moss, on humoferric podzol, (northern taiga)	200	2.0	99.2	29.2	5.2	135.6
Spruce-pine, abundant moss with Oxalis on heavily podzolized soil, (southern taiga)	93	10.0	239.5	65.4	1.0	315.6
Spruce-pine, abundant herbs & ferns, on podzolized soil (southern taiga)	115	15.8	289.6	78.8	0.6	384.8
Alluvial spruce on organic soil over sand (mixed forest zone)	45	15.7	223.7	102.4	-	341.8
Scots pine with Vaccinium vitis-idaea, on sandy podzol (mixed forest zone)	95	3.9	181.8	62.8	-	248.5

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Average annual litter abundance for three different forest types was given as follows: larch 2.7 t/ha; spruce-pine 5.0 t/ha; Scots pine 4.1 t/ha. Biomass, primary production, litter and net growth parameters of different forest types in the boreal zone of the U.S.S.R. were estimated as in the table below.

	Spruce-Holocomium good site	Spruce-Holocomium poor site	Scots pine-Vaccinium good site	Scots pine high moor, W. Siberia
Age (yr)	200	125	71	100
Phytomass (t/ha)	**340.8**	**173.5**	**279.9**	**37.0**
Green portions	21.1	11.5	13.9	15.1
Above-ground, not green	234.6	121.3	202.4	17.9
Roots	85.1	40.7	63.6	4.0
Primary production (t/ha/yr)	**7.9**	**6.0**	**6.1**	**3.4**
Green portions	3.3	4.3	2.4	3.2
Above-ground, not green	3.25	1.3	2.8	0.17
Annual litter (t/ha/yr)	**5.9**	**4.1**	**4.7**	**2.5**
Green portions	2.8	2.7	2.1	2.3
Above-ground, not green	1.8	0.9	2.2	0.12
Roots	1.3	0.5	0.4	0.08
Net growth (t/ha/yr)	**2.0**	**1.9**	**1.4**	**0.9**
Litter layer in soil (t/ha)	-	**25.0**	**44.8**	-

Included in the text is a figure that illustrates changes in above-ground phytomass and litter over a 260 yr period in a pine stand with a **Vaccinium myrtillus** herb layer. Above-ground phytomass increased to nearly 300 t/ha until a stand age of 120 yr, remained constant from 120 to 190 yr, then declined slightly to a new constant level from 190 to 260 yr.

The author presented a composite diagram that related vegetation and soil types to rainfall, potential evaporation, growing season, radiation and mean annual temperatur. for a northwest to southeast transect, from tundra to desert, in the east European lowlands.

1. WALTER, Heinrich

2. 1973

3. Vegetation of the earth in relation to climate and the eco-physiological conditions.

4. Translated from the second German edition by Joy Wieser, the English Universities Press Ltd., London. 237 p

5. a. Northern hemisphere

   b. Pine

   c. Climate/growth (direct relationships, latitude)

6. The true boreal zone commences at the point where the climate becomes too unfavourable for broad-leaved deciduous species. This is recognizable in climatic diagrams as the point where duration of the period with a daily average temperature of more than 10° C drops below 120 days and the cold season lasts longer than 6 months. The northern boundary between the boreal zone and tundra is where there are only 30 days with a daily mean temperature above 10° C and where the cold season lasts at least 8 months.

The mean annual production of organic mass is 5.5 t/ha in the taiga zone, and wood production is 3 t/ha (the latter can reach 5 t/ha in the southern taiga). The largest annual increment is achieved in northern parts of the taiga after 60 yr, but in southern parts of the taiga after only 30 to 40 yr. The phytomass of the tree stratum of pine forests may reach maxima of 270 t/ha and that of the undergrowth in old stands about 20 t/ha. The quantity of litter produced by older stands on their way to maturity can exceed 1,000 t/ha. This is not accumulated, however, but is continuously decomposed until a state of equilibrium between additions and losses of litter is reached at a litter mass of about 50 t/ha. Organic matter accumulates only in the form of peat. Under such unfavorable conditions the annual increase in dry mass of the tree stratum is often less than that of other strata.

The boreal zone has a humid climate, with rainfall exceeding potential evaporation. If surplus water is prevented from draining into rivers, the ground-water table rises and mires are formed. Large expanses of the boreal zone in Euro-Siberia and in North America are very flat so the ground-water table is high. As long as the water table remains more than 50 cm below ground for most of the year, tree growth is possible. Extensive areas of the boreal zone are covered by plant communities on peaty soils and not by the true zonal vegetation, which is coniferous forest. In large areas of Finland more than 40% of the total land is covered by mires, and in places even 60%. The same holds true for the boreal zone of eastern Europe and especially western Siberia which, except in the vicinity of the rivers, is almost entirely covered by swamps and mires. In Kamchatka, Alaska and Labrador, as well as in regions to the south of Hudson Bay, there are also large sections of the boreal forest region dominated by wetland vegetation types.

1. WEBB, Thompson, III

2. 1981

3. The past 11,000 years of vegetational change in eastern North America.

4. Bioscience 31:501-506

5. a. Northern hemisphere

   b. Nil

   c. Climatic change (hypotheses, dendrochronology, proxy data), Treeline studies (climate)

6. Maps of pollen data from east-central North America show: 1) northward movement of spruce-dominated forests from 11,000 to 7,000 years ago and their return southward after 4,000 years ago; 2) eastward movement of prairie until 7,000 years ago and its subsequent retreat westward; and 3) major compositional changes in mixed conifer-hardwood forests after 8,000 years ago.

The trends that began 10,000 years ago of northward-moving spruce, pine and oak and eastward-moving herbs continued until 5,000 to 7,000 years ago. After this period, spruce populations increased both northward and southward, and pine, oak and herbs all moved westward in the northern midwest. This movement of the prairie/forest border reflects not only the effects of long-term climatic changes but also the effects of many short-term changes such as intermittent droughts near Minneapolis 5,000 to 7,000 years ago.

In part, these changes reflect broad-scale climatic changes as the current patterns of atmospheric circulation became established after the final disappearance of a continental ice sheet on North America. Today storms follow a track from Minnesota to Nova Scotia and bring regular precipitation to the area of northern hardwood forests. The westward movement of these forests may reflect the timing for the establishment of this circulation pattern. The development of this climatic pattern probably decreased the frequency of fires in the northern Great Lakes region and contributed to changes in the organic and nutrient levels of the soils.

Current ecological textbooks often describe vegetational change in the restricted terms of primary or secondary succession. They emphasize the importance of autogenic processes in which biological factors such as competition, predation, shade tolerance, or statistical replacement control the order of succession. Such emphasis is natural among scientists who focus on biological processes, just as an emphasis on climatic factors is natural among climatologists. The biological emphasis among ecologists, however, can lead to theories of steady-state conditions for time scales over which such conditions may never have existed in nature.

Continued ...

Webb, Thompson, III. 1981. Continued

Some studies have indicated that the frequency of disturbance by fires or hurricanes is low enough in northern New England to allow steady-state conditions to develop. However, the author points out that climatic oscillations on the scale of centuries to 500 years might be large enough to effect secular trends in forest biomass and composition over the 400 to 600 years required for a steady state to appear after disturbance.

Studies of alpine glaciers have shown not only the well-documented "Little Ice Age" climatic oscillation (ca. 1450 to 1850 A.D.) but also several other comparable short-term climatic oscillations throughout the past 11,000 years. Detailed pollen studies from annually laminated lake sediments show significant compositional oscillations within northern hardwood forests during the Little Ice Age. Although these compositional changes do not necessarily imply any change in the biomass of the forests, a steady state for biomass seems unlikely in light of the recorded changes in temperature and moisture during the Little Ice Age.

In future studies, the unique ability of pollen data to record vegetational change from the scale of continents to the scale of woodland stands will help in understanding how climate, fire, blowdowns, disease, soil development and competition interact to control vegetational dynamics on the scale of centuries to millenia. Although biological and disturbance factors are important, they must be seen as operating within the context of the many continuously varying environmental factors. At the same time, climatic inferences from pollen data must allow for the threshold responses and lags that characterize how biological systems react to climatic change.

The author's maps illustrate changes at 1,000-year intervals across eastern North America, and thus record vegetational dynamics at time and space scales generally neglected by current ecological theory. The author suggests that the challenge now is to develop models that can explain the full spectrum of vegetational changes from those standardly monitored by ecologists in woodland stands to those longer term trends illustrated by the 1,000-year intervals on the author's map.

1. WEETMAN, G.F.

2. 1974

3. The stability of Canadian boreal forest ecosystems.

4. Proceedings of the First International Congress of Ecology, Structure, Functioning and Management of Ecosystems, The Hague, Netherlands, September 8-14, 1974, 414 p

5. a. Canada; Index maps (all in boreal region); all boreal forest sections

   b. Black spruce

   c. Climate/growth (indirect relationships)

6. The tendency for organic matter to accumulate in wet boreal forest sites has been documented from various regions in North America and Europe. The development of sphagnum mosses and the associated deterioration in soil drainage in wet black spruce stands following cutting has been noted often. On upland sites there has been speculation about the lowering of site fertility under ericaceous dwarf shrub vegetation; for example, the shrub, **Kalmia**, on non-regenerated black spruce stands in Newfoundland can lead to increasing immobilization of nutrients in the unincorporated humus layer and to pan formation and paludification in soils of the site. The presence of the raw humus layer has long been known to be associated with shortages in available nitrogen supplies to trees.

The role of epiphytic feather mosses, such as **Hylocomium splendens** and **Pleurozium schreberi**, in acting as traps for incoming nutrient supplies in dust and precipitation has been recognized and has led to a realization of their value in building fertility on shallow rocky sites.

On most boreal forest sites, following large scale clearcutting, the temporary removal of vegetative competition for nitrogen and other nutrient supplies leads to lush development of pioneer vegetation and the lack of a need for fertilization of young trees.

The author stressed that problems associated with dynamics of the nutrient cycle on different forest sites must be considered, particularly the turnover rate of organic matter and the proportion of total nutrient reserve in the living biomass. While preliminary calculations by the author indicate that on medium quality sites such losses may be modest, more attention is now being paid to potential losses from drier and wetter sites.

1. WEETMAN G.F. and E. HARLAND

2. 1964

3. Foliage and wood production in unthinned black spruce in northern Quebec.

4. Forest Science 10:80-88

5. a. Canada; Index map NM-18; Quebec; 8.1a

   b. Black spruce

   c. Biomass (tree)

6. Foliage and wood production of a 65 year old upland stand of Picea mariana were described in this paper. Although an exact location for the study site was not given, it was approximately at 50° N in Quebec.

Weights of the above-ground portions of black spruce trees were as follows:

Component	Oven dry weight (kg/ha)
Stems with bark	74,157
Live branches	10,791
Needles	8,556
Total tree	93,504

The mean annual productivity of boles and present canopies was 1,558 kg/ha/yr. The average annual weight increments in stemwood production per kilogram of dry needles for the last 10 yr are 0.26, 0.31 and 0.34 kg for dominant, intermediate and suppressed trees, respectively. The dominant, intermediate, and suppressed trees represent 30, 58 and 12%, respectively, of the total dry needle weight per hectare. Thus the lower efficiency of the needles of dominant and intermediate trees is more than offset by their large needle weight. The sum of the products of the average needle weight and volume increment per kilogram of needles by tree classes give a calculated annual stand increment of 5.48 m^3/ha. Dominant, intermediate and suppressed trees contributed 25, 62 and 13%, respectively, to this total stand growth in the 10 yr preceding measurement.

1. WEIN, Ross W.

2. 1978

3. The role of fire in the degradation of ecosystems.

4. IN: M.W. Holdgate and M.J. Woodman, Editors, The breakdown and restoration of ecosystems, Plenum Press, New York. p. 193-209

5. a. Northern hemisphere

   b. Nil

   c. Climate/growth (indirect influences)

6. For purposes of this paper, degradation was considered to exist when ecosystem components do not recover to the expected degree during the normal fire frequency period. Fire has been an evolutionary force in many ecosystems and it has been recognized only recently that some ecosystems depend on fire for long term stability. Fire is generally considered to be a positive force but the author noted that most fire research has been conducted in areas with high fire frequency. The long term effects of increased fire frequency for areas with naturally low fire frequency are not well documented.

1.. the discussion that followed the presentation of the paper it was noted that fires could be separated into two basic types; catastrophic fires that have a low frequency but destroy almost all biomass, and short term fires that occur frequently but with less destruction of biomass.

1. WHITE, E.J.

2. 1974

3. Multivariate analysis of tree height increment on meteorological variables, near the altitudinal tree limit in northern England.

4. International Journal of Biometeorology 18(3):199-210

5. a. Great Britain

   b. Birch, Scots pine

   c. Climate/growth (direct relationships)

6. The response of trees to their environment may be expressed in a number of different ways. Tree ring widths near the base of the trunk are a measure of tree response and have frequently been studied in relation to climate. When the girth of the trunk is still small, it is often easier to examine height increment, as in the present study. Previous research had suggested that height increment depends more on inherent trends than on annual fluctuations of environment. However, the present study of Scots pine, birch (Betula pubescens) and rowan (Sorbus aucuparia) in the northern Pennines (alt. 580 m, 54 14 N, 02 23 W) suggest that much of the variation in height increment is determined by the environment.

The meteorological variables examined were: screen min temp. (°C); screen temp. 09:00 hr (°C); turf mean temp. (°C); soil temp. 10 cm at 09:00 hr (0°C); no. days since start of growth; day length (h); sunshine (h); potential evapotranspiration (cm); smoothed potential evapotranspiration (cm); windspeed (m/sec); rainfall (cm); relative humidity at 09:00 hr (%).

The author carried out a principal component analysis in which five components accounted for 87% of the total variation measured by the 12 meteorological variables. The first component was an expression of energy contrasted with the number of days since the start of growth; the second component was a measure of soil temperature contrasted with windspeed. The third component was an index of mild, stormy weather; the fourth and fifth components were measures of mean potential evapotranspiration and rainfall, respectively. The table on the next page summarizes the results of orthogonalized regression of height increment of each tree species on the first five principal components of the meteorological variables.

Continued ...

The table below lists the percentage variability in height increment of each species associated with each of five components, as defined on the previous page.

	Component					Total % variability significantly accounted for
	1	2	3	4	5	
Scots pine	47.0**	0.56	7.83**	1.67	5.43*	60.3
Birch	31.3**	19.1**	7.28**	0.63	0.39	57.7
Rowan	52.3**	9.15**	5.27**	4.23*	1.75	70.9

** significant when P is less than 0.01
* significant when P is less than 0.05

The first principal component (energy) accounts for the greatest part of the variation in growth. For Scots pine and rowan, a small but significant part of the variation in height increment is associated with the relatively insignificant components 5 and 4 respectively. Rowan appears to benefit significantly from cool soil, in contrast to birch. Scots pine and rowan respond to energy and soil temperature early in the season, while birch shows a complex dependency. In the middle of the season, response is dominated by the component expressing rainfall, though not quite significantly in Scots pine. The lack of significant correlation in the middle of the season between Scots pine and rainfall may be because Scots pine was growing on the most peaty soil with the greatest water content or because transpiration, and thus dependence on rainfall, is reduced by the xeromorphic leaf structure of pine.

1. WHITTAKER, Robert H.

2. 1975

3. Communities and ecosystems.

4. MacMillan Publishing Co., Inc., New York. Second Edition. 385 p

5. a. Northern hemisphere

b. Nil

c. Climate/growth (direct relationships, latitude)

6. Although this text contains only limited data directly from the boreal forest, some of the author's conclusions relating to forest productivity have widespread application, including the principles listed below.

1. Net production of stable forests on sites of relatively favourable moisture conditions are convergent over a wide range of warm-temperate to cool-temperate climates.

2. There is a point in cool-temperate climates beyond which productivity decreases more rapidly toward the low values of alpine and arctic climates. Because of this, mean productivity approximately doubles from the highest elevation to the lowest elevation forests.

3. Although net productivity of climax deciduous and evergreen forest is similar in warm-temperate climates, in the transition to the arctic and alpine climates evergreen forests have an adaptive advantage over deciduous forests, which is expressed in higher productivity.

The author reproduced a curve by Lieth (1975) that related mean annual temperature to net primary productivity. This curve suggests an upper limit of about 3,000 $g/m^2/yr$. Productivities decrease along the temperature gradient from tropical to arctic regions and in the middle of the curve, productivity somewhat more than doubles with an increase of 10° C in mean annual temperature. Decreasing length of the growing season toward colder climates may have as much to do with this as temperature itself.

There is a general tendency for biomass, as well as productivity, to decrease along decreasing moisture and temperature gradients. Biomass values of mature forests are mostly in the range of 20 to 60 kg/m^2, woodland 4 to 20, grasslands 0.5 to 3, and deserts and tundra 0 to 2. Biomass ranges are similar for tropical and temperate forests except for the largest of all forests, which are certain temperate rain forests. The relation of biomass to productivity is conveniently expressed as the biomass accumulation ratio, the ratio of dry weight biomass to annual net primary productivity. Such ratios for above-ground parts of plants increase through the sequence of terrestrial biome types, and vary from 1 to 3 in grassland, 10 to 30 in woodlands and 20 to 50 in mature forests.

Continued ...

Biomass and productivity parameters for the entire circumpolar boreal zone, in relation to the earth's total terrestrial area, are summarized in the table below.

	Boreal forest	Total continental
Area 10^6 km^2	12.0	149
Net primary productivity, per unit area		
Normal range ($g/m^2/yr$)	400-2000	-
Mean ($g/m^2/yr$)	800	773
Net primary production for entire area (10^9 t/yr)	9.0	115
Biomass per unit area		
Normal range (kg/m^2)	6-40	-
Mean (kg/m^2)	20	12.3
World biomass 10^9 t	240	1837
Chlorophyll 10^6 t	36.0	226
Leaf surface area 10^6 km^2	144	644
Litter mass 10^9 t	48.0	111

1. WILLIAMS, Jill

2. 1975

3. The influence of snowcover on the atmospheric circulation and its role in climatic change: an analysis based on results from the NCAR global circulation model.

4. Journal of Applied Meteorology 14:137-152

5. a. Northern hemisphere

   b. Nil

   c. Climate (air masses, precipitation), Climatic variation (regional, temporal, precipitation)

6. Snowcover can act as an anomalous heat sink for the atmosphere. As an indication of its role as a heat sink it has been pointed out that late snowcover around 50 00 N, persisting until late April, can deny the atmosphere as much as half or more of the radiation it would receive without the snow. Evidence suggested that extensive snowcover plays some part in maintaining a cold trough in the upper troposphere which favours persistence of the snow.

The development of a cold trough aloft over the Hudson Bay - Great Lakes region is associated with extensive snowcover. There is a positive feedback loop involving the abnormal extent of snowcover and atmospheric circulation in which the snowcover acts to intensify the east coast cyclogenesis and Canadian anticyclone and they in turn help to maintain the snowcover. It is thought that the anomalous global weather pattern of 1972 and 1973 could be the result of an increase in snowcover extent from 1971 to 1973. It seems, therefore, that extensive snowcover can influence the atmospheric circulation.

The author's model indicated that if a snowcover could last through a summer, the probability of a much higher snowcover in the next year rises substantially. This is the beginning of a positive feedback process: snow surface with high albedo leading to tropospheric cooling, which causes a cold upper vortex and enhanced snowfall.

1. WOETHANN, Niels

2. 1978

3. Variation of climate, as indicated by extended temperature records from Denmark, the Faroes and Greenland (including a short review of sun-weather relationships).

4. IN: Knud Frydendahl, Editor, Proceedings of the Nordic symposium on climatic changes and related problems. Danish Meteorological Institute, Copenhagen. Climatological Papers 4:212-222.

5. a. Northern hemisphere

   b. Nil

   c. Climatic change (hypotheses), Climatic variation (regional, temporal)

6. This paper describes variations of climate in the order of 100 yr or less. Possible relationships between solar events and weather are reviewed. The Little Ice Age corresponded with the Maunder Minimum, a period in history of the sun with exceptionally few sunspot observations. Just before the beginning of the Maunder Minimum the sun's equatorial rotation speed had increased, completing a rotation one full day faster than it had in 1625, which was a year with sunspot activity comparable with the level of today. During the period 1965 to 1976 the magnitude of the equatorial solar rotation speed, averaged annually, was inversely correlated with the annual relative sunspot numbers. It has been suggested that the increase of the equatorial solar rotation speed may be responsible for the earth's present climatic conditions.

Sun-weather relationships on an intra-annual time scale have been investigated by several authors. In these investigations attention has been concentrated on the influence of the structure of the solar-interplanetary magnetic sectors. Studies have indicated that 300 mb low pressure trough systems which enter, or are formed in the Gulf of Alaska, two to four days after a sharp rise in geomagnetic activity, tend to be of larger than average size. Other researchers have also investigated relationships between solar winds and meteorological responses. Studies of the response of the zonal geostrophic wind at the 10 mb surface to solar activity fluctuations found a significant response of the stratospheric circulation to solar activity for nearly all latitudes between 10° and 80° N at a frequency corresponding to half the synodic rotation period of the sun.

The author analyzed monthly mean temperatures from approximately 1870 to 1975 at four locations, Copenhagen and Vestervig in Denmark, Thorshavn in the Faroe Islands and Godthab in Greenland. A general increase of temperature during approximately the first half of the 20th century was apparent at Thorshavn, Godthab and Vestervig. The increase was less pronounced at Vestervig. An interesting feature of the moving averages

Continued ...

Woetmann, N. 1978. Continued

is that winter and summer averages from the beginning of the 20th century until 1969 were out of phase. The 'out of phase' feature results in periods with relatively warm winters and relatively cold summers (1893-1912 and 1921-1940), and periods with relatively warm summers and relatively cold winters (1922-1941 and 1950-1969). In other words, the degree of coastal climate in Denmark seems to have varied from a more pronounced coastal climate, roughly from 1910 to 1930, to a less pronounced coastal climate, roughly from 1940 to 1969.

Other studies of the frequency of zonal and meridional circulation patterns over the northern hemisphere indicated that the frequency of zonal circulation patterns increased from around 1910 to 1930 and decreased from 1931 to 1960.

The author reviewed a theory of meridional circulation for the northern hemisphere that coincided with the results of this study. The average temperature at the surface of the northern hemisphere increased from 1900 to 1941 and decreased from 1942 to 1972 in all seasons. It has been demonstrated that despite the hemispheric increase of temperature from 1900 to 1941, there were wide areas with decreasing temperature, and despite the he-ispheric decrease of temperature from 1942 to 1972, there were wide areas with increasing temperature. The increase or decrease of the average temperature to a large extent was determined by temperature variations at high latitudes. Temperature changes at the surface of the polar cap in winter are associated during a warming period with stronger meridional circulations, or weaker meridional circulations during a cooling period, around the major mean pressure systems at sea level in high latitudes.

1. WONG, C.S.

2. 1978

3. Atmospheric input of carbon dioxide from burning wood.

4. Science 200:197-200

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels)

6. The atmospheric input of carbon dioxide from burning wood, in particular from forest fires in boreal and temperate regions resulting from both natural and man-made causes and predominantly from forest fires in tropical regions caused by shifting cultivation, is estimated to be 5.7×10^{15} g of carbon per year as gross input and 1.5×10^{15} g of carbon per year as net input. This is a significant amount as compared to the fossil fuel carbon dioxide produced from the utilization of oil, gas, coal and limestone.

To determine the contribution of boreal and temperate forests to atmospheric carbon dioxide totals, annual average fire losses from Canada and the United States were used (Table 1). The computed inputs of carbon dioxide into the atmosphere from fires in boreal forests and nonwooded areas are listed in Table 2.

Table 1. Annual average forest fire losses in Canada, 1959 through 1968.

Type	Area burned ($10^{10} m^2$)
Vegetation	
Salable timber forest	0.235
Young growth	0.198
Cutover land	0.056
Nonforested area	0.402
Causes	
Man-caused	0.436
Lightning	0.562

The atmospheric CO_2 reservoir of 670×10^{15} g of carbon is roughly in short-term equilibrium with two very large fluxes of annual gross output and input. The natural input, about 160×10^{15} g/yr,

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includes respiration by land biota at 63 x 10^{15} g/yr, decomposition of terrestrial detritus at 37 x 10^{15} g/yr, respiration by ocean biota at 25 x 10^{15} g/yr, and decomposition of open ocean detritus at 35 x 10^{15} g/yr. The nonfossil burning input, mainly anthropogenic, amounts to 5.7 x 10^{15} g/yr and the fire and man-made inputs total 11.0 x 10^{15} g/yr. Corresponding input estimtes by Baes et al. (1977) were 7 x 10^{15} and 12.0 x 10^{15} g/yr.

In contrast to the gross input, the net CO_2 input is essentially anthropogenic in nature: fossil fuel combustion at 5 x 10^{15} g/yr and new forest clearing in the tropics at 1.5 x 10^{15} g/yr. The natural net input is close to zero, because the natural carbon cycle is roughly in equilibrium. The gross natural CO_2 input by forest fires, detritus decomposition, and plant respiration is balanced by CO_2 uptake for plant photosynthesis. Thus, the gross fluxes do not contribute to the atmospheric CO_2 increase, although the net CO_2 fluxes do.

Table 2. Input of CO_2 into the atmosphere from nonfossil wood burning and other sources.

Source	Carbon: Gross input (10^{15} g/yr)	Carbon: Net input (10^{15} g/yr)
Fires in boreal forests & nonwooded areas	0.07	0.0
Fires in temperate forests & nonwooded areas	0.4	0.0
Tropical shifting cultivation on land already in use	3.0	0.0
New tropical forest clearings	1.5	1.5
Fuel wood burning	0.2	0.006
Paper waste burning	0.08	0.0008
Soil carbon loss in agriculture	0.3	0.3
Soil carbon loss on burning	0.4	0.02
Desertification	0.05	0.05
Urbanization of farmland	0.01	0.01
Fossil fuel burning	5.0	5.0
Respiration of land biota	63.0	0.0
Decomposition of land detritus	37.0	0.0
Respiration of ocean biota	25.0	0.0
Decomposition of ocean detritus	35.0	0.0
Total	approx. 171.0	approx. 6.9

1. WONG, C.S.

2. 1978

3. Carbon dioxide - a global environmental problem into the future.

4. Marine Pollution Bulletin 9:257-264

5. a. Northern hemisphere

   b. Nil

   c. Climate (carbon dioxide levels)

6. The carbon dioxide problem is one of man's interference with a natural cycle. Since the advent of agriculture, the standing forest phytomass has been converted to cultivated land with a change from an estimated 1.2 x 10^{18} g of carbon in the virgin state to the present-day 8.27 x 10^{17} g of carbon on a global basis. Since the beginning of industrialization about 1850, man's energy source from wood carbon has been rapidly replaced by more concentrated forms of fossil carbon. The economically recoverable quantities of fossil carbon total approximately 10^{19} g of carbon, or ten times the living phytomass today. The atmospheric CO_2 content in 1974 was estimated to be about 7 x 10^{17} g of carbon, about the same size as the phytomass carbon reservoir. By releasing this huge deposit of fossil carbon, accumulated over 500 million years on earth, into the atmosphere over a relatively short period of a few hundred years, man is creating a change not known to exist in the earth's history.

The effects of CO_2 increase in the atmosphere are mainly climatic. The gas is almost transparent to the incoming solar radiation of short wavelengths. This visible radiation, on striking the solid earth, is converted into heat energy, which is radiated back to outer space as invisible infrared radiation. However, this infrared back-radiation is strongly absorbed by CO_2 at the absorption band of 13 to 17 microns, thus warming up the atmosphere. This mechanism is often referred to as the "green-house effect".

There is a discrepancy between the fossil fuel burning input into the atmosphere (2.3 ppm) and the observed atmosphere CO_2 increase (1 ppm). Even if there is no other significant source of CO_2, only about half of the CO_2 from fossil fuel burning remains in the atmosphere. The rest must have been taken up by the ocean, in the land phytomass, or both. It has been accepted until recently that the atmospheric CO_2 increase is rather constant. However, for unknown reasons, fluctuations in the observed atmospheric CO_2 increase have been sizeable.

The most controversial question at present is whether there exists an additional major net source of CO_2 other than fossil fuel burning. Up to about 1975, the consensus was that burning of oil and coal was the major input. The suggestion of land biota as a major CO_2 source into

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the atmosphere was first proposed in 1967. The land biota consists mainly of land vegetation, with only minor contribution from animal biomass. The best estimate of the standing crop of land phytomass is about 8.27×10^{17} g of carbon with the majority of the carbon stored as tropical wood and a smaller quantity as temperate and boreal wood. Tropical rainforest accounts for 42% of the global land phytomass, tropical seasonal forest 14, temperate evergreen forest 10, temperate deciduous forest 11, boreal forest 13, woodland and shrub 2.7, savanna 3.3, swamp and marsh 1.6, temperate grassland 0.8, cultivated land 0.8, and tundra and alpine meadow 0.3%.

CO_2 is released into the atmosphere when plant material is burned. If the land biota is a source of CO_2 additional to fossil fuel burning, the ocean has to be a sink for CO_2. Estimates of input of CO_2 into the atmosphere from wood burning are summarized below in relation to other sources.

	Gross input (10^{15} g/yr)	Net input (10^{15} g/yr)
Wood burning		
Fires in boreal forests & nonwooded areas	0.4	0.0
Fires in temperate forests & nonwooded areas	0.2	0.0
Tropical shifting cultivation on land already in use	1.0	0.0
New tropical forest clearings	0.5	0.5
Fuel wood burning	0.2	0.006
Paper waste burning	0.08	0.0008
Soil and land		
Soil carbon loss in agriculture	0.3	0.3
Soil carbon loss on burning	0.4	0.02
Desertification	0.05	0.05
Urbanization of farmland	0.01	0.01
Fossil fuel		
Fossil fuel burning	5.0	5.0
Natural biological processes		
Respiration by land biota	63.0	0.0
Decompositon of land detritus	37.0	0.0
Respiration by ocean biota	25.0	0.0
Decomposition of ocean detritus	35.0	0.0
Total	168.0	5.9

The most serious lack of knowledge in the carbon cycle is in the detritus reservoirs of dead carbon, both on land and in the marine environment. The total detritus standing mass is estimated to be 3×10^{18} g of carbon, thought to be approximately equally distributed on land and in the ocean, but the amounts are poorly known.

1. WONG, C.S.
2. 1979
3. Carbon input to the atmosphere from forest fires. - Reply
4. Science 204:210
5. a. Northern hemisphere
   b. Nil
   c. Climate (carbon dioxide levels)

6. The crux of the carbon cycle is as crude as whether the terrestrial phytomass is a net source of CO_2 or not. A review of the fluctuating estimates of the input of CO_2 from the land phytomass indicated a possible concensus in the recent literature toward a significant but much smaller contribution of CO_2 from wood burning. Comments by Fahnestock (1979) helped further this downward revision of the nonfossil CO_2 contribution.

Using a combustion efficiency of 0.2 based on Fahnestock (1979), the author estimated that the total net carbon input from nonfossil wood burning and other sources amounts to about 0.6×10^{15} g/yr, or about 12% of the fossil fuel sources. This lower limit is in line with conclusions of other investigators.

The author stressed that it is important to obtain more data on the combustion efficiency of forest wood, a highly variable quantity between 0.2 and 0.75, affected by such environmental factors as the intensity of heat, humidity, wind, the duration of burning, and the nature of woody material. Moreover, the charred remains of the unburned wood after fires may ultimately contribute through decay processes as net CO_2 input to the atmospheric CO_2 reservoir, over a longer time scale and with a similar difficulty in its quantification. Uncertainties in assessing other heterogeneous land carbon add immense difficulty to an understanding of the carbon cycle based on phytomass and soil detritus carbon in our terrestrial environment.

1. WRIGHT, H.E., Jr. and M.L. HEINSELMAN

2. 1973

3. The ecological role of fire in natural conifer forests of western and northern North America.

4. Quaternary Research 3:317-328

5. a. Canada, Alaska; Index maps (all in boreal region); All boreal forest sections in Canada

   b. Nil

   c. Climate/growth (indirect influences)

6. Included in this review is a summary of factors, processes and effects of fire common to coniferous forests. Many of these processes relate to biomass production in the boreal forests of North America.

The effect of fire as a regulator of dry matter accumulation can be summarized as follows:

1. Fires directly recycle the carbon of herbs and shrubs, and the foliage, bark, and wood of trees. Conversely, without fire, as the stand matures and decomposition fails to keep pace, these components gradually accumulate. The proportion of dry matter consumed varies with fire type, intensity, and frequency.

2. Fires may consume the carbon in litter and humus layers and sometimes remove accumulated peat. Conversely, in the absence of fire these layers increase to the extent that decomposition fails to balance accumulation. The imbalance is related to temperature, precipitation, evaporation, latitude, elevation, topography and many local site factors.

3. Following severe fires the killed trees may constitute a large reservoir of dead organic matter.

4. Fires may stimulate increased net primary production through changes in the physical-chemical environment.

5. Fires may retard the accumulation of humus and peat for a period after burns through effects on soil nutrients, temperatures and permafrost. The effect is complex because of interactions with evapotranspiration and groundwater levels on the sites where accumulation is most rapid. Fire can be viewed as the controller of major ecosystem processes. In fire-dependent ecosystems fire is a major factor in nutrient cycling and energy flow. Rates and pathways are influenced by fire frequency and intensity. In the absence of fire, nutrient cycles and energy flow may be partially or severely blocked by incomplete decomposition of biomass. The accumulation of biomass, in turn, builds up fuel loads, which make lightning ignitions and high-intensity burns increasingly probable with the passage of time.

1. YAMAMOTO, E., T. IWASHIMA and N. HOSHIAI

2. 1978

3. Change in surface air temperature averaged over the northern hemisphere during the years 1951-1972.

4. IN: K. Takahashi and M.M. Yoshino, Editors, Climatic change and food production. International Symposium on recent climatic change and food production. University of Tokyo Press, Tokyo, Japan. p. 303-310

5. a. Northern hemisphere

   b. Nil

   c. Climatic change (hypotheses), Climatic variation (temporal, temperature)

6. Climatic elements generally have great variability in space and time. However, temperature has less variability than precipitation, and several successful attempts to estimate global temperature conditions have been made. Using long period data from weather stations around the globe, a trend of global temperature warming has been described for the period 1880 to 1940.

This study utilized monthly mean surface air temperatures from 343 weather stations north of 20° S from 1951 to 1972. Several negative temperature anomalies were apparent, and a general tendency of slightly lower temperatures was noted for the entire 22-yr period. Negative anomalies of temperature with durations longer than six months occurred in six periods. The authors found a relationship between severe eruptions of volcanoes and five of the six cold periods. Temperature decreases greater than 0.5° C were found in high and middle latitudes within one year of the volcanic eruptions. Two significant temperature decreases greater than 1.5° C were noted in the winters of 1957-58 and 1965-66. These decreases appeared with time lags of 20 months and 30 months after very severe volcanic eruptions. These severe eruptions may have caused some temperature effects not found in other less severe eruptions.

A detailed investigation of the global dust spread by the Agung erupt... in Bali, in March 1963, was made by other researchers. The authors suggest that the results described in this paper give evidence of the climatic effect of volcanic eruptions. However, the need for further studies, involving more specific climatic data and development of climatic theories, was stressed.

1. YEFIMOVA, N.A.

2. 1971

3. Geographical distribution of the sums of photosynthetically active radiation.

4. Soviet Geography 12:66-74

5. a. Northern hemisphere

   b. Nil

   c. Climate (temperature, insolation)

6. World maps of photosynthetically active radiation (0.38 to 0.71 micron wavelengths) for the entire year and for the growing season have been compiled in this report.

The annual sums of photosynthetically active radiation were found to range between 30 to 40 kcal/cm^2 and 100 to 110 kcal/cm^2. These sums are three to four times lower in the middle and high latitudes than in tropical latitudes. In the boreal region, annual sums of photosynthetically active radiation range from 40 to 50 kcal/cm^2.

The influx of photosynthetically active radiation tends to vary more widely during the growing season than it does on an annual basis. The growing season was defined as the period in which the mean daily temperature remains above 10° C. On the growing season map, sums of photosynthetically active radiation range between 0 to 10 and 100 to 110 kcal/cm^2 during the entire season. This suggests that the temperature factor tends to limit the effectiveness of incoming radiation since the sums of photosynthetically active radiation are high in the summer months even in arctic regions, but are ineffective because of low temperature and the short duration of the growing season. The maps for the growing season thus reflect the combined effect of two factors, radiation and temperature. In most of the boreal regions, annual sums of photosynthetically active radiation during the growing season range from 10 to 20 kcal/cm^2.

1. YOUNG, Harold E.

2. 1980

3. Puckerbrush power.

4. Paper prepared for Meeting of Planning Group 'B' - Growth and production - International Energy Agency, Biomass Energy, North Central Forest Experiment Station, Rhinelander, Wisconsin, p. 1-13

5. a. Maine

   b. Nil

   c. Biomass (tree, shrub/herb)

6. Included in this discussion of the biomass of young deciduous trees and shrubs are figures from biomass inventories carried out in Maine. In hardwood test plots there was a relationship between the average height of the stand and the oven dry weight of wood and bark for the above-ground portion of the woody shrubs and trees. The relationship was approximately 2.0 t/ha, oven dry weight, per 30 cm of average stand height. For a fully stocked mixed deciduous stand that had an average height of 9.0 m, the estimated oven dry weight would be 60 t/ha. To include the stump-root system this estimate should be increased by 1.33.

1. YOUNG, Harold E., Leigh E. HOAR and Theodore C. TRYON

2. 1976

3. A forest biomass inventory of some public land in Maine.

4. IN: H.E. Young, Editor, Oslo biomass studies, University of Maine, College of Life Science and Agriculture, Orono. p. 283-292

5. a. Maine

   b. Mil

   c. Biomass (tree)

6. Biomass studies conducted at the University of Maine have resulted in some generalized approximations concerning forest biomass, as listed below:

1. The moisture content of a complete fresh tree or woody shrub is about 50%. Therefore, the dry weight of the wood, bark and leaves or needles, both above and below ground, is also about 50%.

2. The stump-root system is about 20%, the merchantable bole about 55% and the tops about 25% of the fresh weight of the complete tree or woody shrub.

3. Bark is about 14% of the complete tree on a dry weight basis.

4. The leaves are about 4% of the total weight of hardwoods and the needles are about 11% of the total weight of softwoods on a dry weight basis. There is more variation among softwood species than hardwood species for the proportion of total weight present as foliage.

These approximations make it possible and reasonable to extract from summaries of forest biomass inventories the approximate fresh or dry weight of the major components of trees and shrubs.

1. YOUNG, Harold E., John H. RIBE and Donald C. HOPPE

2. 1979

3. A biomass study of the thinning potential and productivity of immature forest stands in Maine.

4. Complete Tree Institute, School of Forest Resources, University of Maine, Orono, Maine. Life Sciences and Agriculture Experiment Station, Bulletin No. 758, 38 p

5. a. Maine

   b. Balsam fir, Spruce

   c. Biomass (tree)

6. The purpose of this study was to establish the degree of reliability that can be placed in biomass as a means of assessing thinning potential and site productivity of immature forest stands in Maine. Tree species were grouped as hardwoods and softwoods. Balsam fir and spruce were the softwoods harvested in this study.

The sample sites were classified as follows. Wet sites were low wet areas with the water table at or near the surface weeks after the water table has been depressed on mesic sites. Dry sites were on eskers, kames, kame terrace or outwash plains with a 30 to 60 cm overburden of soil that was quite sandy with deep sand and/or gravel underneath. Mesic sites included a range of fine and till soils that were considered normal for Maine.

The authors' estimates are in oven dry tons per hectare for living trees and for standing trees. Weight estimates are for complete trees, from root tips to leaf tips, inclusive. Above-ground biomass and annual above-ground dry matter production for stands of increasing age on three sites classes were estimated as follows:

Above-ground biomass for stems 2.5 cm d.b.h. and larger, exclusive of needles (t/ha)

Stand age (yrs)	Hardwoods			Softwoods		
	Mesic	Wet	Dry	Mesic	Wet	Dry
15	30.3	12.3	12.3	34.8	34.8	34.8
25	57.2	22.4	25.8	54.9	65.0	48.2
35	89.7	34.8	43.7	82.1	81.8	61.7
45	131.2	47.1	66.1	113.2	94.2	76.2
55	181.6	61.7	88.6	149.1	105.4	91.9

Continued ...

Young, H.E., J.H. Ribe and D.C. Hoppe. 1979. Continued

Annual dry matter production in trees 2.5 cm d.b.h. and larger, exclusive of needles (t/ha/yr, oven dry)

Stand age (yrs)	Hardwoods			Softwoods		
	Mesic	Wet	Dry	Mesic	Wet	Dry
15	2.69	1.26	0.90	4.57	4.57	3.63
25	2.42	1.01	1.12	3.48	3.43	2.60
35	2.42	0.94	1.35	2.94	2.62	1.86
45	2.13	0.89	1.61	2.58	1.97	1.57
55	2.06	0.87	1.84	2.35	1.55	1.52

The following table is a comparison of the standing crop of an immature stand and an all-age stand. The estimates are of above-ground portions of trees larger than 2.5 cm d.b.h. exclusive of needles:

Above-ground biomass (t/ha, oven dry)

Age of stand	Hardwoods			Softwoods		
	Mesic	Wet	Dry	Mesic	Wet	Dry
35	89.7	34.8	43.7	81.8	81.8	61.7
170	162.8	192.8	146.4	127.3	166.8	181.6

The following estimates are of above-ground annual dry matter productivity for trees larger than 2.5 cm d.b.h. exclusive of the needles:

Annual above-ground productivity (t/ha/yr, oven dry)

Age of stand	Hardwoods			Softwoods		
	Mesic	Wet	Dry	Mesic	Wet	Dry
35	2.42	0.94	1.35	2.94	2.62	1.86
170	0.95	1.14	0.85	0.74	0.99	1.08

Productivity for all sites was similar for very young softwood stands but with increased age the mesic sites were more productive. Annual dry matter production was greatest at the youngest age class studied for all species and decreased from then on.

1. ZACKRISSON, O.

2. 1977

3. Influence of forest fires on the North Swedish boreal forest.

4. Oikos 29:22-32

5. a. Sweden

   b. Nil

   c. Climate/growth (indirect influences), Climatic change (proxy data), Climatic variation (regional)

6. The frequency of forest fires during the past 600 yr was studied within boreal forest ecosystems in a river valley in northern Sweden. Fire scars on living and dead trees were used for dating past fires. Before fire suppression started in the 19th century the coniferous forest had burned at a mean interval of 80 yr; in contrast, the mean time since the latest fire is now around 155 yr. Fire maintained the diversity and long term stability of the forest and represented a natural factor in the boreal forest ecosystem. Due to efficient fire suppression during the past two centuries, fire is no longer a rejuvenating factor in the forests of northern Sweden. With the fire frequency found for the period from 1901 to 1975 it would take about 3500 yr to burn over an area equivalent to that of the total sample plot area of the present investigation. For the period from 1551 to 1875, before fire suppression methods were introduced to any great extent, the calculated fire rotation was about 100 yr. From being a highly important ecological factor, virtually controlling the vegetational dynamics of the forest in past times, fire became quite a minor factor in the development of the forest communities that have existed from the end of the 19th century up to the present day.

Climatic fluctuations during the past 600 yr represent an important factor affecting the forest fire frequency. In northern Sweden, central inland areas are subject to a higher frequency of thunderstorms than either the coastal or mountain areas, and are thus exposed to a greater risk from forest fires caused by lightning. Climatically, inland portions of the study area have a more continental climate, with warm and dry summers that favour the outbreak of forest fires.

The climatic fluctuation of the 'Little Ice Age', between 1550 and 1850 A.D., probably affected the natural forest fire frequency through changes in precipitation and thunderstorm frequency. The incidence of fires remained fairly high from 1551 to 1875; each year during this period approximately 1% of the forest stands were affected by fire. Data that indicated an increase in fires during the period 1676 to 1700 were not readily explained. Increases in fires due to human activities and recurrent periods characterized by droughts, above-normal air temperatures in summer and dry electrical storms may have contributed to the increase in fire frequency in the period from 1676 to 1700.

Continued ...

Zackrisson, O. 1977. Continued

The more recent fire years of the 20th century, such as 1901 and 1933, are known from the forest fire statistics to have been related to an increase in the frequency of forest fires started by dry lightning thunderstorms connected with stable high pressure systems, with extreme drought and high air temperatures.

The forest fire frequency reported in recent investigations from the northern parts of the U.S.S.R. and from North America are, in general, similar to those noted for northern Sweden, with the exception of the past two centuries. The difference in the past two centuries is probably the result of fire suppression being both initiated earlier and being far more comprehensive in the north of Sweden than in the other forest regions.

1. ZASADA, John C., Keith VAN CLEVE, Richard A. WERNER, John A. McQUEEN and Edo NYLAND

2. 1977

3. Forest biology and management in high-latitude North American forests.

4. IN: North American forest lands at latitudes north of 60 degrees. Proceedings of a Symposium. University of Alaska, Fairbanks, Alaska. p. 137-195

5. a. Alaska

   b. Alder, aspen, white birch, balsam poplar, black spruce, white spruce, willow

   c. Biomass (tree, shrub/herb), Climate/growth (direct relationships, indirect influences)

6. The authors presented a detailed review of site conditions, forest productivity and forest management in boreal forests of Alaska and northern Canada. Their review revealed one major difference in the regional climatic pattern between the Canadian and Alaskan northern forests. In Canada there is a general decline in temperature and growing conditions with increasing latitude. In Alaska, the warmest growing seasons occur in the interior area north of the Alaska Range. Areas south of the Alaska Range have relatively cool summers because of the moderating influence of the ocean. The long summer days are another feature that set this part of the boreal forest apart from more southern areas.

The authors stressed that climatic data from standard weather stations, although of value in describing the regional climate, do not adequately describe local variations and site-specific relationships that are important in forest growth and distribution. In general, the trend from warm, dry frost-free sites to cold frost-dominated sites corresponds with the trend from high to low ecosystem productivity.

Data presented by the authors show the strong influence of nutrient availability upon forest productivity. The differences between river bottom and upland sites are of particular interest. Available P is much lower on a per unit basis on river bottom sites, while N appears to occur in about the same concentrations in both lowland and upland sites. Total available N and P reflect differences in forest floor mass between the sites. A unique feature of these comparisons is the low concentration and small accumulated mass of available P and N in the forest floor of the highly productive balsam poplar ecosystem. The smaller accumulation of forest floor organic matter and total accumulated N and P is attributable to periodic flooding of the river floodplain poplar stands and removal or burial of a portion of the organic matter. Low forest floor nutrient concentration in these highly productive ecosystems

Continued ...

undoubtedly reflects low mineral soil nutrient status and loss of N and P through leaching of the forest floor during flooding. Sufficient P for use by the rapidly developing poplar ecosystems could be supplied by a frequent turnover of the low-concentration soil solutions. However, direct tree root observations show that floodplain water tables are in close proximity to tree root systems, especially during periods of high water level. In combination with capillary rise of water from the water table and withdrawal of water by transpiration, adequate amounts of P may be supplied to tree root systems. The possibility also exists that poplar ecosystems are adapted to low soil P concentrations.

Black spruce ecosystems have concentrations of N and P similar to or higher than those encountered in more productive ecosystems, such as balsam poplar. Although nutrient contents of the forest floor appear high enough to support a more productive ecosystem, controls specific to the black spruce vegetation type, such as reduced decomposer activity caused by low soil temperatures and luxuriant growth of the feather mosses which compete with spruce for nutrients, restrict the portion of the available nutrient pool that can be utilized by the spruce.

In boreal forest ecosystems, mean annual increment of overstory biomass increases up to a point that is determined by species composition and site conditions. The sharp decline in overstory biomass recorded for the later stages is based on successional trends which indicate that, in the absence of disturbance, some forest types (black spruce and floodplain white spruce in particular) evolve toward the non-forested bog. This site degradation is related to declining soil temperatures and increasing water content, which ultimately result in permafrost formation.

Forest floor biomass eventually reaches an equilibrium where decomposition equals annual input in northern forests, generally at least 50 yr in birch and aspen ecosystems and longer in black spruce in interior Alaska. A primary reason for increased accumulation of forest floor biomass is the predominance of moss in later stages of succession, particularly in spruce stands. The moss layers produce significant biomass, which in conjunction with vascular plant litter deposition, results in the thickening of the forest floor. These layers serve as an effective insulator, further reducing forest floor and mineral soil temperature.

Reduction in the soil nutrient pool reflects the incorporation of increasing quantities in the forest biomass. From the trends in overstory and forest floor biomass, it is apparent that the overstory is relatively more important in incorporation of nutrients into biomass in the early stages of the sequence, while forest floor accumulation becomes dominant in later stages of development.

A number of factors interact with these general trends, causing them to be interrupted or revert to earlier stages in this sequence. Two of the

Continued ...

most important are fire and flooding. Fire has been the most important overall disturbance in the north; in conjunction with aspect, it accounts to a significant degree for the patterns of forest distribution. Fires destroy the overstory and forest floor, resulting in the release of significant quantities of nutrients. Surface and subsurface temperatures increase because overstory shading is reduced and organic layer thickness decreased; where permafrost is present, the thickness of the active layer increases. The relative degree to which ecosystem development is set back depends on fire intensity. Following fire, black spruce ecosystems initially would have the potential productivity and rates of nutrient cycling characteristic of warmer, more productive aspen, birch or white spruce ecosystems. Subsequently, the system would revert to a state of lower productivity and reduced rate of nutrient cycling in response to process-controlling variables that are characteristic of black spruce ecosystems.

Flooding, and deposition of silt and sand on river bottom sites, represents a totally different means of altering the trends in concentration of soil and forest floor nutrients. Flooding commonly has its effect without destroying the overstory. The result is that organic layers are buried and silt deposited, increasing the soil nutrient pool and removing the insulating organic matter which depresses soil temperature. The trees and shrubs on these sites possess, to varying degrees, the ability to produce adventitious roots that colonize these layers.

The availability of nitrogen is generally believed to be a factor that limits growth on many sites in the taiga. The total amount of nitrogen in stands that represent extremes in forest development appear to be of the same order of magnitude for all stands. The major differences occur in the distribution of nitrogen between ecosystem components. Based on comparisons from the literature, Alaskan forest systems appear to have significantly more nitrogen tied up in the forest floor than Douglas fir, but less than black spruce in Quebec.

Based on currently available data, long-term nutrient cycling considerations can be summarized as follows. In uplands, black spruce ecosystems typify the slowest cycling rates and are the most nutrient conservative. They also display the lowest tree productivity. White spruce, birch and aspen display higher rates of productivity and nutrient cycling. Birch and aspen display up to threefold higher forest floor organic matter turnover rates than white spruce. A larger annual flux of nutrients occurs in the forest floor in the deciduous forests, while foliage is retained for a number of years (up to 25 yr in black spruce) and more system nutrient capital is recycled within the trees in the coniferous forests. Longer foliage retention and slower forest floor decomposition rates characterize ecosystems that are more nutrient conservative. Uptake of nutrients in the phytomass and nutrient retention in the forest floor and mineral soil, which is an effective

Continued ...

filter, prevent loss of chemical elements important in plant growth. Because of low regional precipitation and the general lack of leaching of soil profiles, these upland ecosystems are relatively closed with respect to nutrient loss compared with river bottom ecosystems.

Ecosystems that develop adjacent to riverways are less conservative with regard to nutrient capital, especially in younger stages of succession. The principle of increasing nutrient retention with age still occurs in these ecosystems. Black spruce typifies the low productivity and slow nutrient cycling ecosystem. White spruce displays higher productivity and more rapid nutrient cycling. Balsam poplar, alder and willow are the most productive floodplain ecosystems and display the most rapid cycling of nutrients. Birch does not occur in continuous forests, and aspen is absent from the immediate floodplain. Regardless of vegetation type, a more dynamic nutrient cycle exists in these ecosystems than in upland sites. Periodic flooding adds nutrients, leaches the soil profile of soluble constituents, and may erode the forest floor. High water tables in stands in close proximity to rivers provide an additional source of moisture and nutrients for tree growth. Dense alder stands may add substantial amounts of nitrogen to the soil (up to 300 kg/ha/yr) in the first five years of development from time zero.

The table below contains the authors' summary of the distribution of biomass (g/m^2, dry weight) for various taiga forest ecosystems in Alaska, in comparison to black spruce in Quebec (Weetman and co-workers) and Douglas fir (**Pseudotsuga taxifolia**) from the Pacific Northwest region.

	Age (yr)	Biomass, dry weight, (g/m^2) Overstory	Forest floor	Roots
Alnus incana (Alaska)	5	1009.8	434.0	590.2
Alnus incana (Alaska)	15	3339.5	1459.8	1521.0
Alnus incana (Alaska)	20	4790.4	2078.2	2473.0
Picea mariana (Alaska)	56	1423.1	8866.4	1245.7
Picea mariana (Alaska)	61	2416.3	13325.9	1040.1
Picea mariana (Alaska)	130	10398.7	11923.5	5169.7
Picea mariana (Alaska)	150	5357.0	7619.0	4689.2
Picea glauca (Alaska)	165	24945.0	19786.0	12401.4
Betula papyrifera (Alaska)	60	11894.8	6877.2	4429.7
Betula papyrifera (Alaska)	120	14763.0	4374.3	5467.8
Populus balsamifera (Alaska)	60	18031.0	2222.7	6678.2
Populus tremuloides (Alaska)	50	4872.0	3728.4	1804.4
Picea mariana (Quebec)	65	10720.0	17650.0	4614.4
Pseudotsuga taxifolia (P.N.W.)	52	19258.0	10466.0	1100.0
Pseudotsuga taxifolia (P.N.W.)	38	8608.0	5607.0	888.0
Pseudotsuga taxifolia (P.N.W.)	450	53000.0	9850.0	7430.0

1. ZAVITKOVSKI, J.

2. 1971

3. Dry weight and leaf area of aspen trees in northern Wisconsin.

4. IN: Forest Biomass Studies, Working group on forest biomass studies Section 25, Growth and Yield, International Union of Forest Research Organizations, University of Maine, Orono, Miscellaneous Publication 132, p. 193-205

5. a. Wisconsin

   b. Aspen

   c. Biomass (tree)

6. Dry weights of the above-ground parts of 42 quaking aspen and 8 bigtooth aspen trees ranging in age from 6 to 45 yr were determined in aspen communities in northern Wisconsin. The best single estimator of foliage and crown dry weights was stem diameter at the crown base, confirming findings of Peterson and co-workers (1970) for the same species. The latter investigators determined biomass relations in a 66 to 89-yr old aspen stand in Alberta. Although their trees were about twice as old as the oldest trees in the Wisconsin study, dimensions were about the same. Superimposition of allometric regressions from the two studies revealed different regression coefficients for dry weights of total (above-ground) tree (0.8993 vs. 0.9901), stem (0.9061 vs. 1.0175), live branches (2.1979 vs. 2.9206), and foliage (1.8229 vs. 2.2422). In all instances the regression coefficients from Alberta aspen trees were smaller and intercept values higher, indicating that for the same value of the independent variables (log diameter at crown base) the small Alberta trees were heavier and had higher foliage and branch dry weight than trees of the Wisconsin study. Some of these differences may not be significant but their consistency in all mentioned components indicates that different relations may exist in young and old trees of the same species.

Percentage of dry weight in stem wood was significantly lower in the dominant trees than in the remaining classes of trees. Trees over 20 yr old had a higher percentage of stem bark than the dominant and codominant trees. No difference, however, was found among the age classes. In general, bark proportion on individual trees increased with height in the tree ranging from about 12% on the low parts of stems to over 50% on the top. The highest percentage of wood with the least amounts of both stem and bark and live branches is obtained from codominant trees followed by intermediate and suppressed trees. The author suggested that research should concentrate on finding methods of growing the smallest possible proportions of dominant trees without materially sacrificing total productivity.

Continued ...

Zavitkovski, J. 1971. Continued

Quantities of foliage expressed as percentage of the total dry weight were negatively correlated with age in all classes of trees. From the maximum of 9.91% in the youngest age class the values decreased to the minimum of 2.44% in trees older than 40 years. In comparison to the latter, Peterson and co-workers (1970) determined an average foliage percentage of 2.2% for aspen trees 66 to 89-yr old, although foliage accounted for about 30% of total (above-ground) tree weight in a 2-yr old aspen stand in Alberta.

1. ZOLTAI, S.C.

2. 1975

3. Tree ring record of soil movements on permafrost.

4. Arctic and Alpine Research 7(4):331-340

5. a. Canada, Alaska; Index maps NR-7/8/9, NQ-7/8/9; District of Mackenzie; B.23a, B.23b

   b. Black spruce, larch, white spruce

   c. Climatic change (dendrochronology)

6. Trees that grow on severely cryoturbed soils on permafrost terrain produce reaction wood in response to tilting of trees by ground-heave movements. In this study, black spruce, white spruce and larch tree discs taken from different earth hummocks showed multiple tilting and recovery. The direction of the tilt was generally away from the centre of active hummocks. The regional pattern of ground movement activity showed periods of high activity and periods of quiescence. At the highest rate of activity 27% of the hummocks showed a movement.

Study sites were located at Inuvik (68 21 N, 126 47 W) and Norman Wells (65 17 N, 126 47 W). The regional pattern was broadly similar in both locations, although there was a two-year lag between the north and the south, with changes occurring earlier in the north. This was especially noticeable in the short-term averages where there was a good correlation between the two regions during the periods 1835 to 1850, 1882 to 1895 and 1930 to 1972. In the intervening periods no consistently common pattern was evident. There was a suggestion of a similar lag in the long-term 20-yr averages of movements.

Climatic data for the area were inadequate to permit correlations between climatic parameters and ground movements. However, an examination of some climatic parameters showed that periods of high ground activity may be related to higher than normal late summer temperatures, higher than normal rainfall or a combination of both.

Heat flow studies at Barrow, Alaska, showed that the mean annual air temperature has increased by 4° C since the middle of the 19th century, and that a cooling trend has taken place beginning about 1950. The warm period in Alaska coincides closely with the period of higher level of ground heating in the Inuvik area between 1847 and 1943 and a cooling trend with a low level of activity since 1943.

1. ZOLTAI, S.C.

2. 1978

3. Soil productivity in the arctic environments of Canada.

4. IN: Proceedings of the 11th Conference International Soil Science Society, Volume 3. p. 348-359

5. a. Northern hemisphere

   b. Pine, larch, aspen

   c. Biomass (tree)

6. The climate of the arctic and subarctic is cold with short growing seasons. Climatic data along a north-south transect in Canada show a gradual warming southward and an increase in the frost-free season. Annual precipitation is very low in the north but increases southward. Annual net radiation is from 5 to 15 kly in the arctic, 16 to 19 kly in the subarctic, and increases to 28 to 31 kly at the northern limit of the boreal forest.

Mean values of live and dead plant biomass of above-ground standing crop from different climatic regions were cited in this paper. An open larch forest in the 'high subarctic' had an above-ground standing crop of 2,308 g/m^2, and a pine site in the boreal forest had a standing crop of 10,127 g/m^2. Estimated mean values of yearly above- and below-ground increment in a boreal aspen stand were 474 $g/m^2/yr$ and 210 $g/m^2/yr$ for a juvenile and mature stand, respectively.

1. ZONN, S.V.

2. 1972

3. Some results and prospects of research on the productivity of forest biogeocenoses.

4. Soviet Geography 13:56-63

5. a. U.S.S.R.

   b. Spruce

   c. Biomass (tree, shrub/herb, moss/lichen)

6. This paper reviews research in the U.S.S.R. on the productivity of forest biogeocenoses. Differences in the amount of litter fall and phytomass from one natural zone to another are analyzed for spruce communities and for stands of various ages.

Annual litter fall in spruce forests and spruce-broadleaf forests of different ages were given as follows.

Soil and forest type	Age (yr)	Annual litterfall (kg/ha/yr) dry weight: Needles, leaves, branches	Moss	Herbs	Total
Middle taiga subzone:					
Spruce-bilberry; thin podzolic soils	17	2,015	220	490	2,725
	38	2,050	730	130	2,910
	110	3,215	480	410	4,105
Spruce, herbs, green mosses; peat-humus-gley soil	17	2,262	50	1,780	4,092
	35	2,570	30	1,720	4,320
	130	2,230	640	1,160	4,030
South taiga subzone:					
Spruce-bilberry; heavily podzolic soil	38	2,020	-	-	-
Mixed needle-broadleaf zone					
Spruce, green moss; turf-podzolic soil	70-80	3,079	-	-	-
Spruce, green moss; turf-podzolic soil	50	3,211	-	-	-

INDEXES

CIRCUMBOREAL GEOGRAPHIC INDEX

NORTHERN HEMISPHERE, GENERAL - 52, 54, 55, 60, 63, 64, 69, 70, 73, 74, 76, 87, 88, 92, 95, 98, 100, 108, 109, 111, 112, 113, 115, 116, 123, 129, 136, 141, 143, 150, 152, 153, 157, 158, 164, 166, 173, 175, 180, 181, 183, 184, 207, 209, 210, 212, 214, 215, 224, 225, 226, 227, 234, 236, 238, 244, 250, 255, 261, 265, 275, 279, 280, 281, 282, 284, 289, 292, 293, 294, 300, 308, 312, 325, 327, 329, 330, 331, 332, 333, 334, 335, 342,

CANADA, GENERAL - 70, 77, 83, 84, 93, 108, 122, 159, 160, 162, 168, 195, 201, 203, 221, 245, 271, 276, 285, 303, 308, 310, 321, 326, 334

ALBERTA - 65, 78, 120, 121, 127, 149, 164, 165, 182, 228, 254, 256, 268, 272, 273, 287, 303, 306

BRITISH COLUMBIA - 96, 97, 103, 121, 238

DISTRICT OF KEEWATIN - 62, 107, 111, 121, 139, 165, 190, 191, 192, 215, 217, 218, 219, 245, 247, 251, 252, 302

DISTRICT OF MACKENZIE - 85, 87, 121, 137, 139, 146, 164, 165, 177, 181, 190, 191, 192, 216, 217, 219, 232, 245, 247, 251, 252, 259, 278, 286, 287, 293, 305, 306, 341

LABRADOR - 107, 128, 155, 158, 172

MANITOBA - 79, 215, 217, 219, 224, 228, 245, 247, 273, 287, 293, 297

NEW BRUNSWICK - 71, 72, 198, 223, 230, 231

NEWFOUNDLAND - 82, 155, 156, 196, 197, 219, 222, 253

NOVA SCOTIA - 198

ONTARIO - 59, 101, 123, 124, 142, 155, 167, 178, 215, 217, 219, 245, 247, 248, 249, 262, 270, 271

QUEBEC - 80, 128, 130, 132, 143, 155, 158, 219, 223, 247, 262, 263, 264, 275, 323, 327

SASKATCHEWAN - 63, 78, 187, 215, 217, 219, 228, 245, 273, 287, 292, 293

YUKON - 81, 87, 134, 176, 177, 277, 305

Continued ...

CIRCUMBOREAL GEOGRAPHIC INDEX (continued)

FINLAND - 53, 102, 125, 139, 151, 165, 172, 173, 174, 186, 188, 189, 193, 194, 195, 199, 205, 206, 207, 239, 240, 242, 243, 258, 269, 288, 289, 290, 298, 299, 309

GREAT BRITAIN - 125, 171, 208, 257, 306, 328

GREENLAND - 138, 206

ICELAND - 206

NORWAY - 81, 102, 125, 170, 179, 186, 188, 199, 206, 207, 235, 242, 257, 258, 289, 290

SWEDEN - 52, 58, 97, 102, 104, 125, 137, 141, 172, 188, 189, 206, 207, 240, 242, 267, 289, 290, 298, 301, 337

UNITED STATES

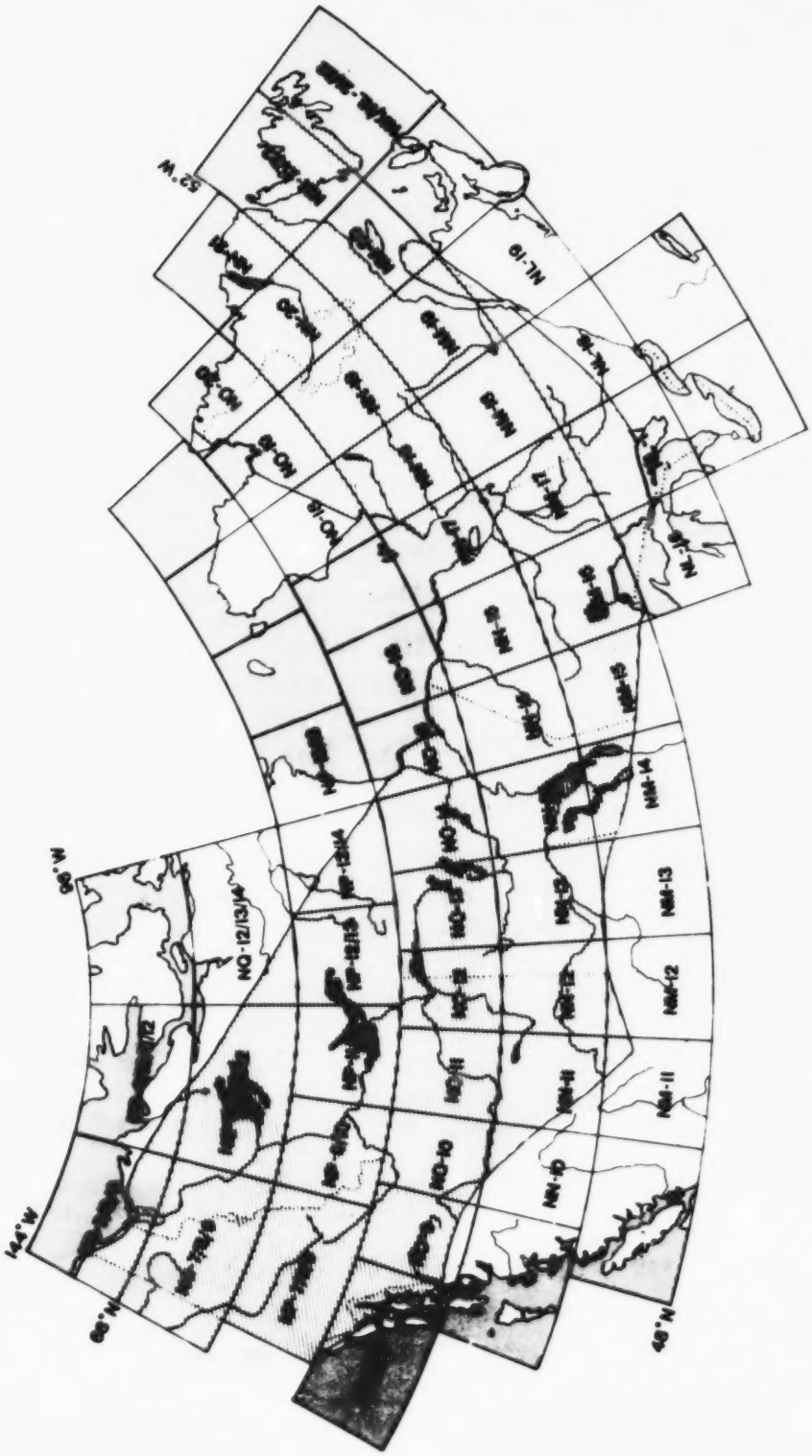
ALASKA - 67, 68, 87, 128, 134, 144, 145, 147, 148, 159, 160, 166, 168, 201, 219, 233, 256, 257, 278, 285, 300, 314, 316, 318, 319, 320, 321, 334, 338, 341

MAINE - 126, 335, 336

MINNESOTA - 57, 61, 66, 101, 215, 219, 221, 267

WISCONSIN - 106, 215, 219, 260, 340

U.S.S.R. - 52, 60, 64, 66, 75, 91, 97, 102, 118, 125, 131, 132, 135, 144, 148, 172, 201, 202, 204, 206, 229, 233, 249, 279, 296, 299, 311, 321, 324, 342


52°W
NL-19
NM-14
NM-13
NM-12
NM-11
NN-10
NO-10
NO-11
NO-12/13/14
96°W
144°W
68°N
48°N

MAP INDEX FOR CANADIAN REFERENCES

Listed by Map Sheet Name and Number from
1:1 000 000 International Map of the World

ALL INDEX MAPS FOR ENTIRE BOREAL REGION IN CANADA - 70, 77, 83, 84, 93, 122, 159, 160, 162, 168, 195, 201, 203, 221, 245, 271, 276, 285, 303, 308, 310, 321, 326, 334

ALL INDEX MAPS FOR ALBERTA - 121, 165, 228, 273, 287

ALL INDEX MAPS FOR BRITISH COLUMBIA - 121

ALL INDEX MAPS FOR DISTRICT OF KEEWATIN - 121, 165, 215, 217, 245

ALL INDEX MAPS FOR DISTRICT OF MACKENZIE - 87, 121, 165, 217, 245, 287

ALL INDEX MAPS FOR MANITOBA - 215, 217, 228, 245, 273, 287

ALL INDEX MAPS FOR NEW BRUNSWICK - 223

ALL INDEX MAPS FOR NEWFOUNDLAND - 155

ALL INDEX MAPS FOR ONTARIO - 124, 155, 215, 217, 245

ALL INDEX MAPS FOR QUEBEC - 155, 223

ALL INDEX MAPS FOR SASKATCHEWAN - 215, 217, 228, 245, 273, 287

ALL INDEX MAPS FOR YUKON - 87, 121

NK-17, Lake Erie - 178
NK-18, Hudson River -
NL-16, Lake Superior - 167
NL-17, Sudbury - 80, 101, 142, 248, 249, 270, 271
NL-18, Ottawa - 80, 132
NL-19, Québec - 71, 72, 198
NK/NL-20, Halifax - 198, 230, 231
NK/NL-21/22, St. John's - 82, 156, 253
NM-11, Kootenay Lake - 96, 103, 127, 182, 256, 268
NM-12, Lethbridge - 256
NM-13, Regina -
NM-14, Winnipeg - 79
NM-15, Lake of the Woods -
NM-16, Lake Nipigon - 59, 167
NM-17, Timmins - 59, 123, 130, 262
NM-18, Lac Chibougamau - 80, 130, 327
NM-19, Chicoutimi - 80
NM-20, Anticosti Island -
NM-21/22, Corner Brook - 82, 156, 196, 197, 222, 253

Continued ...

MAP INDEX FOR CANADIAN REFERENCES (continued)

NN-10, Prince George - 65, 238
NN-11, Lesser Slave Lake - 65, 78, 120, 182, 254, 256, 272
NN-12, Edmonton - 78, 149, 182, 187, 254, 256
NN-13, Prince Albert - 78, 187
NN-14, The Pas -
NN-15, Gods Lake - 219, 224, 297
NN-16, Winisk Lake - 219, 247
NN-17, James Bay - 219, 247
NN-18, Lac Bienville - 130, 219, 262
NN-19, Schefferville - 107, 158, 219, 275, 323
NN-20, Churchill Falls - 107, 128, 158, 219
NN-21, Cartwright - 107, 158, 219
NO-7/8, Sitka -
NO-9, Dease Lake -
NO-10, Fort Nelson - 65
NO-11, Peace River - 65, 254, 256
NO-12, Lake Athabasca - 164, 254, 256, 303, 306
NO-13, Wollaston Lake - 63, 219, 292, 293
NO-14, Southern Indian Lake - 219, 293
NO-15, Churchill - 219, 224, 247
NO-16, Partridge Island - 219, 247
NO-17, Ottawa Islands -
NO-18, Lac Minto - 219, 262, 263, 264
NO-19, Ungava Bay - 107, 128, 143, 158, 219, 247, 263
NO-20, Torngat Mountains - 107, 128, 158, 172, 219
NP-7/8/9, Macmillan River - 81
NP-9/10, Redstone River - 137, 164, 259
NP-11/12, Slave River - 164, 219, 293, 306
NP-12/13, Lockhart River - 181, 190, 192, 216, 219, 232, 251, 252, 293
NP-13/14, Dubawnt River - 62, 107, 111, 139, 190, 191, 192, 218, 219, 247, 251, 252, 302
NQ-7/8/9, Peel River - 85, 164, 176, 177, 219, 277, 305, 341
NQ-9/10/11/12, Great Bear River - 137, 164, 177, 219, 251, 252
NQ-12/13/14, Thelon River - 219
NR-7/8/9, Firth River - 85, 134, 146, 164, 219, 259, 278, 286, 305, 341
NR-9/10/11/12, Horton River - 219

BOREAL FOREST SECTION INDEX FOR CANADA

Listed by Forest Section Numbers from Rowe (1972)

ALL BOREAL FOREST SECTIONS IN CANADA - 70, 77, 83, 84, 93, 122, 159, 160, 162, 168, 195, 201, 203, 221, 245, 271, 276, 285, 303, 308, 310, 321, 326, 334

ALL BOREAL FOREST SECTIONS IN ALBERTA - 121, 165, 287

ALL BOREAL FOREST SECTIONS IN BRITISH COLUMBIA - 121

ALL BOREAL FOREST SECTIONS IN DISTRICT OF KEEWATIN - 121, 165, 217, 245

ALL BOREAL FOREST SECTIONS IN DISTRICT OF MACKENZIE - 87, 121, 165, 217, 245, 287

ALL BOREAL FOREST SECTIONS IN MANITOBA - 217, 245, 287

ALL BOREAL FOREST SECTIONS IN NEW BRUNSWICK - 223

ALL BOREAL FOREST SECTIONS IN NEWFOUNDLAND - 155, 156, 253

ALL BOREAL FOREST SECTIONS IN ONTARIO - 124, 155, 217, 245

ALL BOREAL FOREST SECTIONS IN QUEBEC - 155, 223

ALL BOREAL FOREST SECTIONS IN SASKATCHEWAN - 217, 245, 287

ALL BOREAL FOREST SECTIONS IN YUKON - 87, 121

B.1a - 80, 327
B.1b - 158
B.2 - 71, 72, 80, 198
B.3 - 80
B.4 - 130, 215, 262
B.5 - 130, 219, 224
B.6 - 130
B.7 - 59, 80, 132
B.8 - 215
B.9 - 59, 167
B.10 - 167
B.11 -
B.12 - 158
B.13a - 107, 158, 219, 247, 262, 275, 323
B.13b - 219
B.14 - 215
B.15 - 79, 215
B.16 -

Continued ...

BOREAL FOREST SECTION INDEX FOR CANADA (continued)

B.17 - 65, 127, 149, 182, 254, 256
B.18a - 65, 78, 182, 187, 215, 254, 256
B.18b - 164, 254, 306
B.19a - 65, 120, 182, 254, 256, 272
B.19b -
B.19c - 254, 256, 268, 272
B.20 -
B.21 -
B.22a - 215, 224, 254, 297
B.22b -
B.23a - 137, 164, 256, 303, 306, 341
B.23b - 85, 146, 164, 286, 305, 341
B.24 -
B.25 -
B.26a -
B.26b -
B.26c -
B.26d - 81
B.27 - 63, 107, 139, 164, 181, 215, 216, 219, 232, 251, 252, 292, 293
B.28a - 82, 222
B.28b - 82, 196
B.28c -
B.29 - 82, 222
B.30 - 82
B.31 - 82
B.32 - 62, 82, 85, 107, 111, 128, 139, 143, 158, 172, 177, 181, 190, 191, 192, 215, 216, 218, 219, 247, 251, 252, 259, 262, 263, 264, 278, 286, 302
B.33 - 134, 176, 177, 259, 277, 305

BOREAL TREE SPECIES INDEX

ALDER - 144, 233, 338

ASPEN - 57, 59, 78, 79, 83, 101, 127, 144, 178, 182, 187, 198, 215, 217, 222, 231, 236, 256, 260, 267, 268, 270, 271, 285, 303, 316, 338, 340, 342

BALSAM FIR - 63, 66, 71, 72, 83, 173, 196, 198, 215, 222, 285, 303, 336

BALSAM POPLAR - 78, 83, 182, 187, 285, 318, 320, 338

BIRCH (other than white birch) - 81, 102, 135, 138, 144, 151, 165, 172, 188, 199, 206, 242, 251, 328

WHITE BIRCH - 59, 71, 72, 83, 196, 197, 198, 222, 232, 285, 301, 303, 316, 318, 320, 338

LARCH - 83, 97, 98, 102, 128, 139, 143, 148, 187, 198, 222, 232, 249, 263, 279, 285, 296, 324, 341, 342

PINE (unspecified) - 63, 199, 251, 306, 325, 342

LODGEPOLE PINE - 125

JACK PINE - 57, 83, 132, 167, 187, 198, 215, 217, 230, 231, 248, 249, 285, 292, 293, 303, 306, 321

RED PINE - 57, 83, 189

SCOTS PINE - 58, 64, 102, 104, 125, 137, 139, 141, 143, 151, 165, 170, 172, 173, 174, 186, 188, 193, 205, 206, 233, 235, 239, 240, 242, 243, 257, 267, 269, 279, 288, 289, 296, 298, 301, 309, 324, 328

SPRUCE (unspecified) - 63, 81, 96, 97, 98, 103, 126, 135, 145, 147, 148, 195, 251, 324, 336, 342

BLACK SPRUCE - 67, 68, 71, 72, 83, 85, 111, 130, 139, 168, 173, 187, 190, 191, 192, 196, 197, 198, 203, 215, 217, 218, 219, 221, 222, 223, 232, 245, 247, 252, 262, 263, 264, 275, 285, 286, 292, 293, 297, 300, 302, 303, 305, 314, 316, 318, 319, 320, 321, 323, 326, 327, 338, 341

NORWAY SPRUCE - 66, 81, 102, 125, 137, 151, 165, 170, 174, 188, 194, 205, 206, 239, 240, 258, 288, 309

Continued ...

BOREAL TREE SPECIES INDEX (continued)

WHITE SPRUCE - 57, 71, 72, 83, 128, 134, 139, 142, 144, 146, 149, 166, 168, 172, 173, 175, 176, 177, 187, 198, 215, 217, 222, 232, 245, 252, 256, 257, 259, 262, 264, 277, 285, 286, 300, 303, 305, 316, 318, 319, 320, 321, 338, 341,

WILLOW - 63, 298, 338

SUBJECT INDEX

1. BIOMASS OF BOREAL VEGETATION

1.1 **BIOMASS (TREE)** - 55, 57, 58, 59, 60, 63, 67, 68, 71, 72, 74, 75, 76, 78, 79, 87, 88, 101, 102, 104, 122, 127, 132, 135, 138, 141, 142, 144, 151, 162, 167, 178, 182, 183, 184, 195, 196, 197, 198, 199, 202, 205, 221, 222, 224, 225, 226, 227, 230, 231, 233, 234, 238, 247, 248, 249, 255, 260, 265, 267, 268, 270, 271, 275, 279, 280, 281, 282, 297, 298, 303, 314, 316, 318, 321, 324, 327, 335, 336, 338, 340, 342

1.2 **BIOMASS (SHRUB/HERB)** - 55, 57, 60, 63, 64, 67, 72, 74, 75, 76, 88, 101, 102, 104, 127, 135, 141, 162, 183, 195, 199, 202, 221, 224, 225, 226, 227, 231, 233, 234, 238, 255, 258, 267, 275, 279, 280, 281, 282, 297, 314, 316, 321, 324, 335, 338, 342

1.3 **BIOMASS (MOSS/LICHEN)** - 54, 55, 60, 64, 67, 82, 88, 104, 120, 135, 162, 183, 194, 199, 202, 221, 224, 226, 227, 255, 258, 275, 279, 280, 281, 282, 292, 293, 297, 300, 314, 316, 318, 321, 324, 342

1.4 **FOREST GROWTH AND YIELD** - 83, 84, 85, 125, 187, 196, 197, 256, 276, 306

2. CLIMATE OF BOREAL ZONE

2.1 **CLIMATE (AIR MASSES)** - 69, 70, 85, 91, 107, 108, 112, 131, 159, 162, 191, 204, 210, 212, 214, 215, 216, 217, 219, 229, 269, 310, 330

2.2 **CLIMATE (PRECIPITATION)** - 91, 107, 124, 131, 155, 156, 159, 164, 201, 219, 228, 229, 245, 269, 272, 273, 276, 284, 287, 296, 310, 330

2.3 **CLIMATE (TEMPERATURE)** - 62, 91, 107, 108, 113, 124, 131, 155, 156, 159, 160, 162, 164, 165, 174, 201, 207, 212, 215, 219, 228, 229, 243, 245, 253, 269, 272, 273, 284, 286, 287, 296, 310, 335

2.4 **CLIMATE (INSOLATION)** - 91, 113, 124, 131, 158, 160, 162, 212, 219, 224, 229, 276, 310, 335

2.5 **CLIMATE (CARBON DIOXIDE LEVELS)** - 52, 55, 60, 64, 73, 87, 92, 95, 123, 129, 141, 143, 152, 153, 158, 180, 244, 294, 331, 332, 333

Continued ...

SUBJECT INDEX (continued)

3. CLIMATE/GROWTH RELATIONSHIPS IN BOREAL ZONE

3.1 CLIMATE/GROWTH (DIRECT RELATIONSHIPS) - 53, 65, 66, 74, 76, 77, 80, 87, 88, 92, 98, 115, 120, 125, 126, 128, 134, 135, 137, 144, 162, 164, 165, 166, 170, 172, 173, 175, 176, 184, 186, 193, 194, 201, 202, 203, 207, 215, 221, 223, 224, 227, 238, 239, 240, 243, 245, 256, 257, 259, 261, 263, 264, 284, 285, 286, 288, 290, 296, 298, 300, 303, 306, 309, 312, 318, 320, 323, 325, 328, 329, 338

3.2 CLIMATE/GROWTH (INDIRECT INFLUENCES) - 80, 87, 88, 130, 132, 137, 139, 143, 144, 150, 168, 181, 188, 195, 201, 203, 206, 215, 221, 236, 239, 245, 251, 262, 263, 264, 265, 271, 277, 285, 303, 305, 308, 309, 314, 319, 320, 321, 326, 327, 334, 337, 338

3.3 CLIMATE/GROWTH (MICROCLIMATE) - 80, 81, 120, 131, 134, 175, 179, 188, 245, 262, 264, 300, 314

3.4 CLIMATE/GROWTH (LATITUDE) - 55, 80, 81, 85, 115, 125, 128, 131, 134, 137, 139, 144, 145, 146, 147, 157, 166, 172, 174, 175, 184, 188, 199, 206, 207, 216, 219, 221, 223, 224, 227, 238, 240, 242, 243, 245, 261, 264, 269, 285, 288, 298, 301, 312, 320, 325, 329

4. CLIMATIC CHANGE IN BOREAL ZONE

4.1 CLIMATIC CHANGE (HYPOTHESES) - 60, 61, 64, 70, 87, 88, 96, 98, 100, 103, 109, 111, 112, 113, 116, 118, 130, 136, 139, 158, 180, 181, 188, 189, 190, 192, 209, 210, 212, 214, 215, 228, 250, 252, 257, 269, 278, 279, 289, 293, 294, 299, 302, 325, 330, 334

4.2 CLIMATIC CHANGE (DENDROCHRONOLOGY) - 52, 70, 87, 96, 97, 98, 103, 128, 136, 137, 143, 144, 145, 146, 147, 148, 149, 166, 171, 172, 175, 176, 177, 189, 190, 191, 192, 207, 235, 239, 240, 257, 259, 263, 289, 290, 292, 298, 299, 303, 306, 308, 309, 320, 325, 341

4.3 CLIMATIC CHANGE (PROXY DATA) - 61, 62, 70, 96, 97, 98, 103, 109, 111, 112, 113, 116, 118, 123, 128, 130, 136, 137, 139, 143, 148, 149, 150, 158, 164, 166, 171, 175, 180, 189, 190, 192, 201, 207, 208, 210, 212, 214, 215, 228, 235, 251, 252, 257, 263, 271, 275, 277, 278, 290, 299, 301, 302, 303, 308, 311, 320, 325, 337

Continued ...

SUBJECT INDEX (continued)

5. CLIMATIC VARIATION WITHIN BOREAL ZONE

5.1 CLIMATIC VARIATION (REGIONAL) - 65, 69, 70, 81, 85, 107, 108, 118, 128, 144, 155, 156, 157, 160, 162, 164, 165, 166, 170, 189, 201, 206, 207, 212, 215, 223, 224, 228, 243, 245, 253, 254, 259, 271, 272, 273, 285, 287, 310, 320, 321, 330, 337

5.2 CLIMATIC VARIATION (TEMPORAL) - 70, 87, 88, 98, 100, 106, 107, 109, 116, 118, 136, 137, 139, 152, 166, 170, 172, 173, 189, 206, 212, 214, 215, 228, 238, 242, 243, 254, 269, 271, 279, 289, 299, 310, 311, 320, 330, 334

5.3 CLIMATIC VARIATION (TEMPERATURE) - 65, 81, 85, 98, 106, 107, 109, 116, 118, 128, 136, 137, 144, 155, 156, 160, 166, 172, 189, 207, 212, 228, 242, 243, 245, 253, 271, 272, 285, 287, 289, 310, 334

5.4 CLIMATIC VARIATION (PRECIPITATION) - 65, 85, 107, 118, 128, 132, 155, 156, 212, 228, 253, 254, 272, 285, 287, 310, 330

6. GROWING SEASON OF BOREAL ZONE

6.1 GROWING SEASON (LENGTH) - 77, 106, 121, 124, 131, 162, 174, 193, 195, 205, 207, 223, 227, 240, 242, 245, 257, 272, 273

6.2 GROWING SEASON (DEGREE-DAY TOTALS) - 77, 85, 93, 121, 124, 174, 205, 207, 243, 269, 288, 320, 323

6.3 GROWING SEASON (FROSTS) - 77, 93, 106, 121, 124, 131, 164, 273

7. TREE-LINE STUDIES OF BOREAL ZONE

7.1 TREE-LINE STUDIES (GROWTH) - 85, 134, 138, 139, 144, 145, 146, 147, 172, 173, 175, 176, 188, 189, 190, 192, 206, 218, 219, 232, 239, 240, 245, 247, 256, 257, 263, 286, 296, 298, 305, 323

7.2 TREE-LINE STUDIES (CLIMATE) - 81, 85, 98, 108, 111, 128, 134, 139, 143, 144, 145, 146, 147, 148, 157, 165, 166, 172, 173, 175, 176, 177, 181, 188, 189, 190, 192, 201, 204, 206, 218, 219, 235, 239, 240, 243, 245, 247, 251, 252, 256, 262, 263, 264, 269, 278, 286, 298, 301, 302, 311, 312, 320, 321, 323, 325

POOR

QUALITY

ORIGINAL